Home Built Sonar

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Table of Contents

Preface

The do-it-yourself movement is very well established in almost all areas of life. It's hard to think of anything that you can't learn to build or fix yourself. When I decided to build a side-scan-sonar, I didn't realize how spoiled I was. Most of my other interests are covered by thousands of books, magazines, websites, and videos. I own dozens of books about my different interests, but when I tried to collect information about do-it-yourself sonar, I found almost nothing.

I didn't find any hobbyist level explanations or how-it-works manuals. I purchased all the available books, both new and vintage, and soon found that I was not really the intended reader. I wanted an intelligent, laymen's explanation of the different parameters of a sonar system, without being either too simplistic, or going into dense mathematics. The books that I reviewed cover all the different aspects of a sonar system, but were written for a professional environment. They all describe full sized equipment, built for the Navy or science, with big budgets and state-of-the-art engineering. These books don't even mention the possible use of inexpensive components and home built electronics. The information that I wanted is there, but I had to pick it out, bit-by-bit, and relate it to the system that I wanted to build.

By distilling the information from all my sources, along with cut-and-try backyard research, and some lucky guesses, I was able to get this sonar system working acceptably. I decided to write this book of instructions, based on what I have learned building the sonar system. I have tried to write the type of explanation that I didn't find when I looked for it; a technical description that is not too shallow and not too deep. Included here, is enough information to duplicate the system, adjust it for optimum function, and have a reasonable understanding of how it works. It is a how-to guide, not a textbook.

This is a set of instructions, but without specific blueprint type drawings. It is a suggested method of building a sonar system with the essential details specified and explained. The instructions are not rigid, step-by-step, but a general description of how the prototype unit was built. I have tried to illustrate the details with pictures. This book is for the resourceful and innovative person who can duplicate and improve on a design and doesn't need detailed instructions.

I have included some electronics and electromechanical theory that applies to sonar transducers and some discussion about testing the system. The circuits are briefly explained, but some knowledge of electronic circuitry is assumed.

The operation and interpretation of side-scan sonar in searching bodies of water is a vast subject and very little is included here. In the process of building and testing the unit you will become expert at using your sonar. I haven’t tried to write a detailed operation manual, but a few suggested methods of adjusting and using the system are included.

I have included some sample paper recordings, taken in my local area, to illustrate what to expect from the system. These recordings show spots where the system has been tested during my research. It takes practice to get everything set up and adjusted correctly and evidence of me changing adjustments is visible on the recordings.

Although you can use this unit for serious purposes, it is designed to search for fun! There is lots of junk, and some treasure, out there in the ocean, waiting to be found.

System Introduction

Side-scan sonar is one of the fundamental tools for searching the ocean floor and many professional models are available for different purposes. Some units can show the image of a gun lying on the bottom of a lake while other units can view shipwrecks lost on the floor of the Atlantic. The principles are similar but the physical appearance is very different. The small units used by law enforcement for search and rescue may fit in a suitcase and be deployed from a skiff, while a large ship is required to tow the full sized ocean searching units. It all depends on the requirements of the user, the level of technology, and the financial backing available.

The common factor with all side-scan-sonar equipment is high cost. This equipment is necessarily built in small numbers by specialty companies and their customers are government, military, and large companies. When high performance items are manufactured in small quantities, the engineering cost is divided among a very few customers. Another problem is the fast deterioration of electronic equipment around salt water. Few units survive long enough to become available on the used market. You don't see much side-scan sonar equipment at yard sales.

Most weekend divers or amateur treasure hunters would love to have a side-scan-sonar. Some companies claim to cater to weekend treasure hunters, but their equipment is still more expensive than a decent boat. Sometimes a worn-out unit is for sale on eBay, but that's as good as it gets.

I am one of those weekend divers and I have thought about side-scan-sonar and other searching equipment for many years. There was no chance of buying one of the professional units, so I decided to use my skill with electronics and build one from scratch. This book contains plans and instructions to duplicate the unit that I built. I have included complete information about the system including: fish, electronics, and display.

Several versions of this system have been built and tested on known wreck sites. I have gradually improved the performance by designing and redesigning the various circuits and physical makeup of the system. My dive buddies and I have dived on items that were located, using this equipment, and would be impossible to find using only a fish-finder.

The design objective was to create a unit with respectable performance using off-the-shelf components and materials. A secondary objective was to keep the cost reasonable, and comparable to the cost of other equipment used by divers. This unit is best suited to help find those items that are of interest to divers. This means large items: reefs, shipwrecks, submerged patches of kelp, old piers, pipelines, etc.

This unit will not draw a photo-like picture

of a wreck or allow you to read the ships name, but it does have the capability of finding the wreck. It works great to quickly locate a site that you have only approximate information about. If your dive “buddies” won’t reveal the location a dive site, you can find it yourself with this system. For recreational diving, it is nice to see the general layout of reefs so you can jump in at the most interesting spot. It is also fun to explore the inside of a harbor from an underwater view.

This design avoids the high cost of commercial units in several ways. The use of a low frequency greatly simplifies the transducer construction. The drivers are cheap, heavy duty industrial parts designed for use in ultrasonic cleaning equipment. While they don’t provide high resolution images, they make up for it in brute force. The physics of sound in water favors low frequencies and this unit has decent range for its size and power.

Most of the commercial units have active electronics in the fish. This is necessary for them because of the high frequencies that they use. They transmit out of both sides of the fish with two independent transmit and receive channels. To avoid sending two, high power, high frequency, signals through the tow cable, they generate the transmit power in the fish. The two received signals are sent to a control unit on the boat using multiplex techniques. The fish becomes very valuable since it caries two expensive, high frequency transducers and most of the electronics. If the fish is lost or damaged, it is a real disaster.

My design has no active electronics in the fish. The only component in the fish is the transducer, which you fabricate from easily replaceable parts. You can relax, knowing that if the fish is lost or damaged, you will simply build another one! Not counting your labor, the cost of the fish is quite low.

The low operating frequency means that transmit and receive signals can be sent through the tow cable without appreciable loss. Special electric cable is not needed and simple “lamp cord” wire, from a hardware store, is very adequate for the 26 KHz frequency. The keep it simple philosophy has been followed throughout the design.

The fish transmits out of only one side. This greatly simplifies the construction. The single, relatively large, transducer fits nicely in the fish and allows for a window into the back of the transducer. You can monitor the watertight integrity like you do with a clear camera case. Although the fish transmits out of only one side, the actual area covered in a search is not that much less than with some commercial units. It is simply all on one side and not on both sides of the boat.

The display unit is where some effort and time resulted in big savings. I decided to use a modified fish finder as my display. This eliminated the use of a computer and software in the system. I picked a high quality unit and stripped all the original electronics out. New electronics was designed to operate the system and maximize the potential performance of the display.

Those experienced fishermen who once used the moving paper fathometers will remember that they have many advantages. The paper recording is a permanent record, which you can write notes on and analyze later. Modern computer age people may scoff at the mechanical operation of the paper transport, but it represents a very high degree of engineering.

The resolution and dynamic range is as good as many small LCD displays. Unlike a computer, it is not in danger from splashing salt water and, of course, it has perfect sunlight readability.

There are numerous fish finders of this type available on eBay and in junk stores. The recording graph paper may be an endangered species, but a plentiful supply shows up on eBay. When you buy the fish finder, you often get some spare rolls, and you might find yourself buying a worthless fish-finder, just to get those spare rolls! If you contemplate building this unit, you should begin by buying

Vintage graph paper fish finders

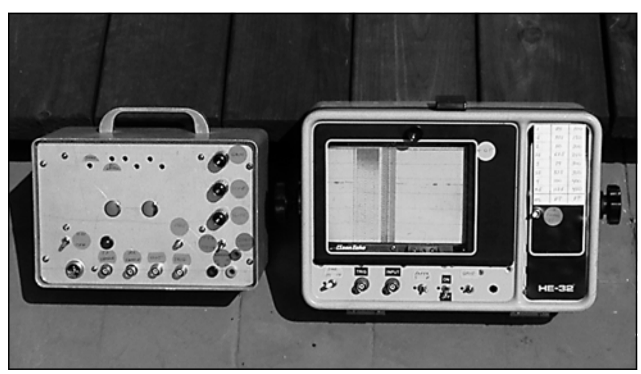
up a supply of paper and some fish finder units. I have a box full myself. The paper actually lasts a long time, if you have the paper speed set to the minimum necessary. The selection and modification of the fish finder is discussed in another section.

I understand that these sonar units will be built by persons who are innovative and not afraid to experiment. I believe this book contains an adequate explanation of the system, but I haven't detailed every nut and screw. The pictures and drawings contain most of the information, even without my narration. Any person who undertakes this project is most likely capable of figuring out the details and will probably deviate from my methods anyway!

If your area of expertise is electronics, the schematics, parts list, and written explanation of the circuits is all you need. I have organized the circuitry on five boards, but you can build it any way you want. For best results, purchase my bare circuit cards and parts kit. Then you will have a working system with almost no effort.

If you are not an electronics person, you will need to team up with such a person. There is no sonar electronics available off-the-shelf, or in kit form, so we are stuck with building it from scratch. Although it is not difficult for persons with electrons in their blood to understand this circuitry, this is not a beginner electronics project. The testing and adjustment requires some test equipment and the experience to use it.

When building the system, there are two possible configurations: The original fish-finder case can house the display related electronics, and a separate enclosure built to house



Prototype sonar system

the receiver-transmitter. Alternately, the paper transport can be removed from the fish finder

case and an entirely new enclosure built to house all the system components. Unfortunately all the components of the sonar system probably will not fit in the old fish-finder case.

I kept the fish finder case as original and installed the circuitry that concerns the paper display in it. There is plenty of room for that part of the installation where the original circuit boards were located. Another box was utilized for the transmitter-receiver which is more bulky.

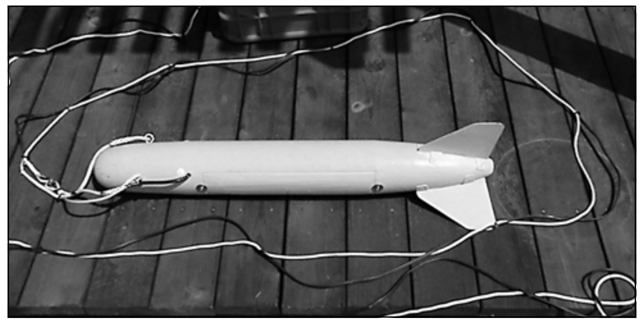
Sonar installation

The fish-finder case will have a nice old fashioned look and simple mounting on a boat. People seeing your boat, with vintage fish-finder, will assume that you are hopelessly lost in the past, but in reality, you have a one of a kind sonar system.

On a small boat where it may get splashed, the original fish finder case will be hard to beat. You can install the other box where it will be sheltered. If you build an entirely new enclosure, you are on your own as far as design. Another possibility is to make it into a table top version, with the paper display on the top, if the boat has a suitable surface to set it on.

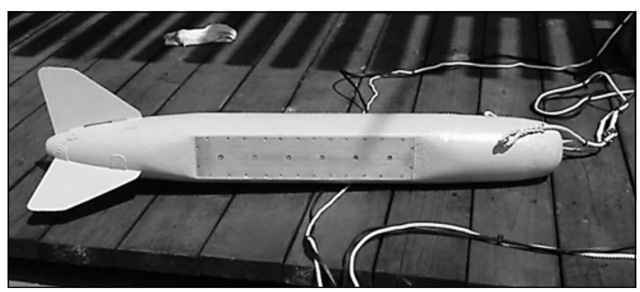
The Fish

The fish is a vehicle designed to carry the transducer through the water at the desired depth and speed. Since the transducer is built to optimize the sound transmitting characteristics and not the hydrodynamic characteristics,



The fish and towline

it will not work to simply drag it through the water. The fish contains the transducer and gives it directional stability, weight, and an efficient shape. Of course a boat can tow anything through the water, given enough power, but the idea is to tow with a minimum of resistance. This way the fish will tow at reasonable speeds with a light force on the tow cable.

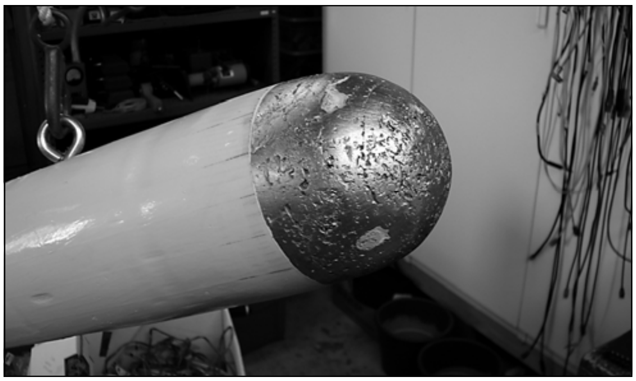


The sound plate

The fish is designed to carry the transducer below any temperature layers close to the surface. The sound path will curve if it passes through a thermocline due to the difference in velocity of sound in water of different tem-

peratures. These layers are usually most dramatic close to the surface. In a deeper layer of consistent temperature, the sound will propagate horizontally and achieve the maximum possible range.

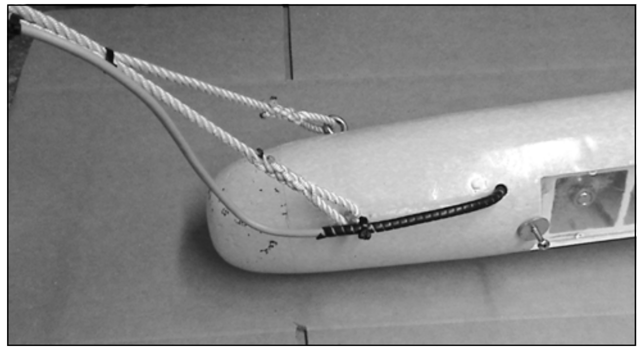
A fish can be designed to dive either by dynamic force using fins with a downward angle or simply weighting it so that it sinks.



The 10 pound cast lead nose

The latter method is much easier to implement. The fish has the weight concentrated in the nose and the harness attached behind the center of gravity and buoyancy. When the boat begins to tow the fish forward, the fins cause the tail to lower and the fish to straighten out. There is a balance of force between the weight tending to pull the nose down and the fins tending to force the nose up. The path of least resistance exists when the fish is horizontal. The overall negative buoyancy tends to sink the fish, while the tow cable tends to pull it to the surface. The depth of the fish depends on the boat speed, length of cable, weight of the fish, and the hydrodynamic resistance of the fish and cable.

The harness is attached to two eyescrews equal distance back from the nose. This allows the transducer to be adjusted for the desired beam inclination. The beam transmits from the



The harness in normal towing position

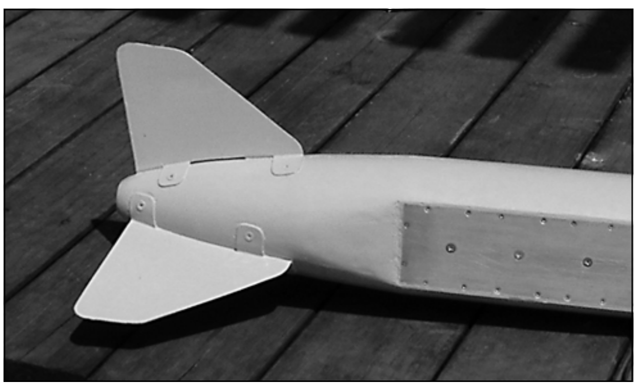
sound plate, out the side of the fish, and is wide in the vertical dimension. This means that the beam will have some effective response above and below the line normal to the sound surface. Depending on the depth of the water and the range of the expected target, the fish can be adjusted to optimize the beam angle. This adjustment is simply done by changing the relative length of the two harness lines and using tie wraps to maintain the adjustment setting.

I chose to construct the fish out of wood because it is easy to work with, rugged, cheap, easy to finish, and easy to modify when necessary. To save money, I used the basic pine boards available at home supply centers. I went through a stack of boards and picked some nice straight pieces. The glue is waterproof polyurethane construction glue which is inexpensive and quite water resistant. The fish is painted with oil based paint. Although it will not stand constant immersion in water, it will survive well with drying after intermittent usage. If you contemplate more rigorous usage, you should build the fish out of a better wood and use marine grade paint and adhesives.

The fins are not too critical except that they must not impart any turning or roll moment to

the fish. This would cause the fish to skew or rotate when moving through the water and point the beam where you don't want it! Be sure they are attached accurately on the fore and aft line. The area of the fins must be sufficient to positively force the nose in the forward direction and not allow the fish to drag sideways. Fins that are too large will not degrade the performance, so I gave them plenty of area. The fish must be stabilized in both the vertical and horizontal axis. Four fins would be the most efficient but three fins will work well as long as they are large enough. With three fins the fish will sit nicely on a deck.

The fins are cut out of sheet steel with tabs bent, drilled, and counter bored to accommodate flat head wood screws. The tabs are shaped to the contour of the fish to maintain a smooth surface. The sheet steel was chosen over aluminum for its ease of working and bending. The tabs must be bent and re-bent while being fitted to the body of the fish. Aluminum cannot be repeatedly bent without becoming brittle. The steel fins are heavily painted and only require touch up occasionally to fix rust. If you are going first class and have good metalworking facilities, stainless steel would be the best material to use. The fins are mounted far back on the body of the fish to give plenty of steering moment.



A three fin system allows the fish to sit on a deck without damage

The nose weight is cast out of lead and screwed and glued to the front of the fish. Four diagonal screw holes are drilled in the lead casting and counter bored to accommodate long wood screws. The holes are filled after attachment. The water flow must be smooth around the nose and across the sound surface. If there is turbulence, the resulting noise might be picked up by the sound surface and lessen the signal to noise ratio. The rough surface of the lead casting should be filled with epoxy filler, sanded and painted smooth. The transition from the lead to the wood should be very smooth. The method of casting the lead to the exact size, in a mold, is described in another section.

The harness is secured to the wood body of the fish with two long eye screws. Alternately, brackets with multiple smaller screws could be used. The eye bolts should be stainless steel and have small eyes to lessen the water resistance. The harness line is spliced to the eye bolts and passed around a thimble with equal length on each side. Tie wraps are placed around the two lines to secure the position of the thimble. The harness is made from a length of nylon line.

The tow line is an important factor in the performance of the sonar. I used yacht quality 3/16 inch nylon line which is rated at about 900 lbs breaking strength. Since the electrical cable cannot stretch, the nylon line must be a high quality type that has a minimal percentage of stretch. The electrical cable is attached at intervals with tie wraps to the nylon line. A

little slack is allowed in the electrical cable between each attachment point to accommodate stretch. A small shackle is used to join the line to the harness thimble.

The electrical cable is spliced to the transducer lead using a water proof splicing technique illustrated in another section. The connection must be absolutely water tight and able to stand the high voltage output of the transmitter. A water proof connector could be used here, to allow the fish to be detached easily from the cable, but I chose to skip this expensive, troublesome component. In practice, the cable is kept with the fish in a milk crate and washed after each use.

The electrical cable is ordinary lamp cord from a home supply store. I used the heavy duty 18 gauge which is very rugged and cheap. It has thick insulation and two equally massive conductors. Although this cable is unshielded, and a shielded cable would be better, the expense and difficulties did not justify using shielded cable.

It is hard to find a suitable shielded or coax cable that is strong, flexible, and will stand up to marine usage. The outer insulation of coax cable is usually thin and water intrudes through the smallest crack. The cable is quickly ruined when water wicks through the entire length. The coax cable that uses aluminum foil as a shield is stiff and corrodes quickly if water enters. The radio and TV type of coax, such as RG-58, is not very flexible and tends to kink. If you wish to use a shielded cable, there is professional microphone cable available which has thick rubber insulation and looks rugged enough. This is the two conductor shielded cable used in studio sound equipment set-ups.

The slot in the wood structure of the fish is sized to hold the transducer with a slight gap all around. The slot is smooth inside and painted like the outer surface. The paint on the inside of the slot keeps the wood from absorbing water which is free to enter the space around the transducer. The transducer is glued to the slot edge, around the metal sound plate, flush with the surface of the fish, and trimmed as smooth as possible. The water should flow without any interruption around the nose of the fish and across the sound plate. The turbulence across the top of the fish, due to the harness attachment, will not be picked up by the transducer. The transducer is glued at both ends on the back, but the side gaps are not sealed. This allows water to drain out after use and avoids water becoming trapped beside the transducer and soaking the wood. Don’t try to completely seal around the transducer because the pressure at depth will eventually force water past the glue seam and soak the wood internally. The glue used to install the transducer should be a flexible type, not hard epoxy, to avoid cracking the lexan transducer case when the wood shrinks or swells.

The fish is contoured for smooth water flow across the sound plate

The transducer can be easily removed for experimental changes or for repair by simply

cutting the glue line around the aluminum plate and the two ends on the back. This is another reason not to use hard epoxy glue or completely fill the space beside the lexan box with sealant. Sooner or later it needs to be pulled out.

The transducer is assembled from lexan plastic and aluminum plate. The sound plate holds the six piezoelectric drivers in a row and conducts their sound output to the water. The drivers must be in a dry environment and the lexan box serves as water proof enclosure. The wire connection passes through a waterproof stuffing seal and is connected to the tow cable with a waterproof splice. The lexan box is sized to be the same width as the aluminum plate and tall enough to clear the tops of the drivers. The fish is sized so that the aluminum plate will be flush with one side and the box top will be somewhat inset on the other side. A wood cowling is shaped to cover the lexan side and is held in place by two screws and washers. The wood cowl maintains the hydrodynamic shape of the fish, but can be removed easily to allow inspection of the interior of the transducer. Any water intrusion can be discovered before damage is done.

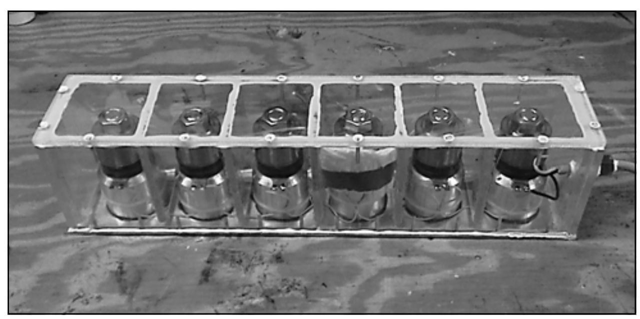
The lexan box is a pressure vessel and must be strong enough to resist to water pressure at depth. I used ¼ inch material and included bulkheads between each driver to stiffen the enclosure. The aluminum plate is secured with screws and sealant to the lexan. If deep operation is contemplated or more rugged construction is needed, thicker material can be used.

The fish can be designed to transmit either to the left or to the right. When using an indicator with a moving paper which moves from right to left, it is easier to visualize the situation with the fish transmitting to the right. There might be a reason why you need left-looking sonar or you might want to construct one of each kind! The display system options are discussed in another section.

The fish is not critical in any dimension. The size is based on what is necessary to hold the transducer and travel through the water efficiently. There is plenty of opportunity to experiment with any aspect of the design. The design presented here works and is cheap and easy to construct.

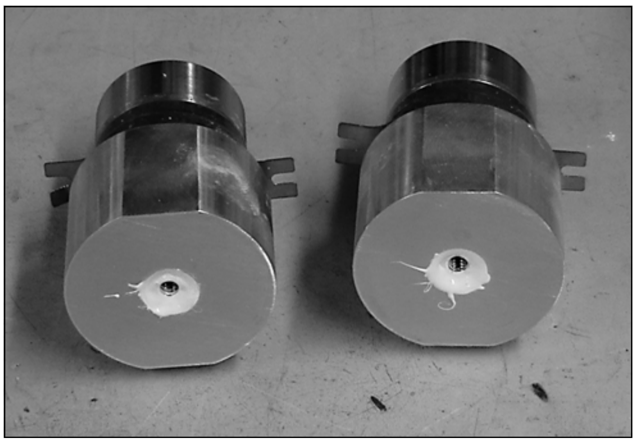
The Transducer

The design of a sonar starts with the physical and electrical qualities of the transducer. The fish must be designed to carry the transducer, and the electronics must interface to it. The choice of transducer must be settled before the design can proceed. For the amateur builder, the cost of the transducer is also a limiting factor on the overall design. Many companies make sonar transducers, either for their own side-scan products, or as generic parts. These professionally designed parts are available, but my do-it–yourself instinct would not permit buying a costly specialty part until I had tried to build it myself.



Transducer assembly ready for installation

I used off-the-shelf components and hardware store materials to put together the inexpensive transducer described here. Physically the transducer is a linear array of six drivers all bonded to an aluminum plate. The back side of the plate, with drivers attached, is contained in a water tight lexan enclosure to provide the necessary electrical and sonic isolation. When the transducer is housed in the fish, the sound plate contacts the water and transmits ultrasonic energy. The linear array creates a narrow sonic beam which is suitable for side-scan sonar. This is not the ultimate transducer, nor is it comparable to the professional units referred to above, but it is capable of respectable performance when teamed with matching electronics.

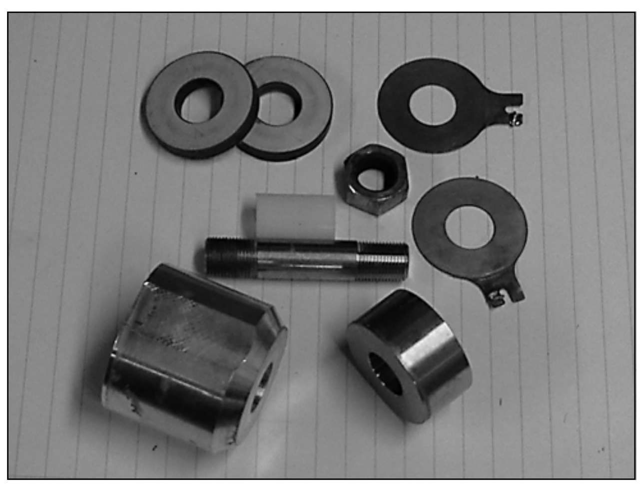


Two of six drivers used in the transducer

I used driver units designed for ultrasonic cleaner equipment. When attached to the bottom of the cleaning tank, and a high power ultrasonic voltage is applied, these drivers vibrate the cleaning fluid to the point of cavitation. I reasoned that these drivers, with their high power capability, could be made into a sonar transducer. Since these are mass produced, industrial parts, the cost is low, and an array of six drivers is very affordable. They are available in several standard frequencies and I chose the 28 KHz version.

The 28 KHz number refers to the frequency of resonance when the driver is operated in air without a mechanical load. When it is driving a load, the resonant frequency will change slightly. The sonar electronics is designed to be tunable, around this range of frequencies, and must be adjusted to closely match the transducer.

The Langevin type driver is an assembly of two metal masses connected by a bolt and two discs of piezoelectric material compressed between. The bolt passes through a hole in the center of the piezoelectric discs. The metal masses are machined with flat surfaces that exactly match the diameter of the piezoelectric discs. The bolt passes through the center without touching the piezoelectric discs and is adjusted to a very precise tension with a large nut. The piezoelectric material alters its physical thickness, in response to alternating current electrical stimulus, and minutely varies the strain on the bolt. If the frequency of the electrical input matches the mechanical resonant



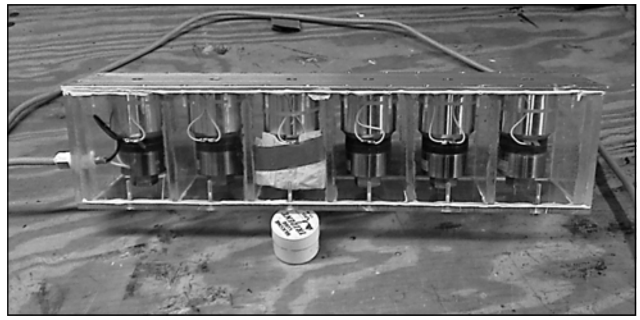
A disassembled driver

frequency of the bolt and two masses, a very pronounced oscillation will take place, with the bolt acting as a spring between the two masses.

One electrical connection is applied to a thin metal terminal sandwiched between the piezoelectric discs. The other electrical connection is to the metal masses and bolt which is contacting the outer sides of the two piezoelectric discs. Thus the piezoelectric discs operate in series mechanically and in parallel electrically.

Of course, the actual movement of the masses is small, but when you consider that the bolt is 12mm stainless steel, it is obvious that a lot instantaneous force is involved. This is a very efficient way to convert electrical energy to mechanical motion. To draw useful output from this driver, one of the masses is drilled with a mounting hole and is bolted to the output load. This drilled mass is aluminum and is lighter than the other mass which is made of steel. The heavier mass will vibrate, freely, in air, and transmit force via the bolt to the output load. In this case, the output load is the sound plate which contacts the water. The characteristics of the output load influence the exact resonant frequency of the system.

Water is a very “stiff” load, and in mechanical terms, is a high impedance load. To efficiently drive ultrasonic power into water requires a driver with an equally “stiff” output. This means a driver that is a good impedance match to water. The Langevin driver happens to be ideal for this purpose. The actual movement of the sound plate is very small, but it is driven with incredible force via the bolt and vibrating mass. The efficiency of converting electrical energy to mechanical force is good because the frictional and electrical losses are minimal. Steel is very elastic and the piezoelectric material is also very efficient. Unlike drivers based on electromagnetic operation, there is little resistive loss.



A package of desiccant is enclosed inside the transducer

Six drivers are connected to the sound plate and driven in phase with the signal from the power amplifier. Since the drivers are closely matched in mechanical construction, they will resonate together and drive the sound plate along its entire length. The result is a unified “piston” effect which forms a well defined beam. Physical laws determine the beam width according to the length of the array in wavelengths. This refers to the wavelength of the sonic signal in water at the operating frequency.

Transmitting the sonar signal is only half the story. The returning echo must be received. When the sound plate is vibrated by sound signals originating in the water, at the resonant frequency, the drivers will oscillate and alternately compress and relieve the piezoelectric discs. The piezoelectric discs will generate an electrical signal proportional to the intensity of the sound. In this way the transducer serves as the receiving hydrophone for the sonar. The optimum resonant frequency

for transmitting will be the same as the most efficient receive frequency. The directional qualities will be similar in receiving as in transmitting.

The high efficiency referred to above means that little power is absorbed in the drivers. If power is applied to a bare driver, not connected to a mechanical load, a very sharp resonance will be apparent. This is also known as a high-Q factor and means that all the energy is circulating within the driver with no place to go. With no load, very little input power can be applied before reaching the maximum safe deflection of the vibrating masses. If a load, which absorbs energy, is attached to the driver, the energy has a place to go and the Q is reduced in proportion to the transfer of power. This is the situation when the driver is part of the transducer and immersed in water. The power is transmitted into the water and radiates out from the sound plate.

Electrical measurement of the input of the driver will reflect the mechanical situation. With no mechanical load, the input measurements show a high-Q, low impedance load. With a mechanical load, which absorbs power, the input measurements will show higher impedance and lower-Q. This change of electrical load is a lucky situation for the amateur designer. The electrical measurements of impedance and Q are relatively easy compared to measuring power or sound intensity in the water. The change in impedance and Q is proof that power is being delivered to the water. The efficiency of the power transfer is closely related to the amount of change of impedance.

Except for the actual values of impedance, the behavior of six drivers, connected in parallel and installed on the sound plate, is similar to the behavior of a single driver. The change of impedance, Q, and resonant frequency can be observed when the transducer is immersed in water.

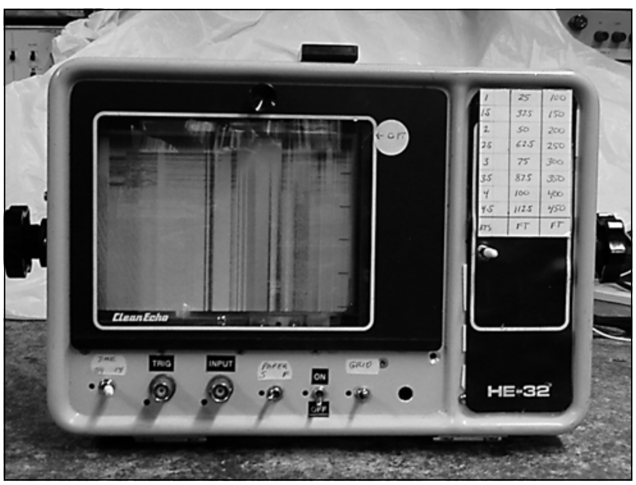
The electrical load of the transducer, when it is immersed in water, should be the optimum load of operation of the power amplifier. In other words it should be a good impedance match. This is not so simple, when, as explained above, the load changes in response to changes in frequency and mechanical load on the driver. The easiest way to accomplish this goal is to finish the transducer and measure its impedance in actual conditions. Then design the power amplifier output circuit to match the measured impedance. The result that you want is a good electrical impedance match from the amplifier to the driver and a good mechanical impedance match from the driver to the water.

The transducer has another characteristic which must be compensated for. The drivers with their piezoelectric material are a capacitive load. The power amplifier requires an essentially resistive load for best operation. This is a common situation in electronics and is solved by introducing an opposite reactance in the circuit. The solution is to connect an inductor in series with the transducer which counteracts the capacitive reactance. Thus, when the transducer is driven at its resonant frequency, the load will be a nearly resistive load.

The design and adjustment of the sonar system is a juggling act with multiple variables. All of the above factors must be considered to arrive at a system that works. The details of measuring the characteristics of the drivers and finished transducer are contained in another section.

The Display

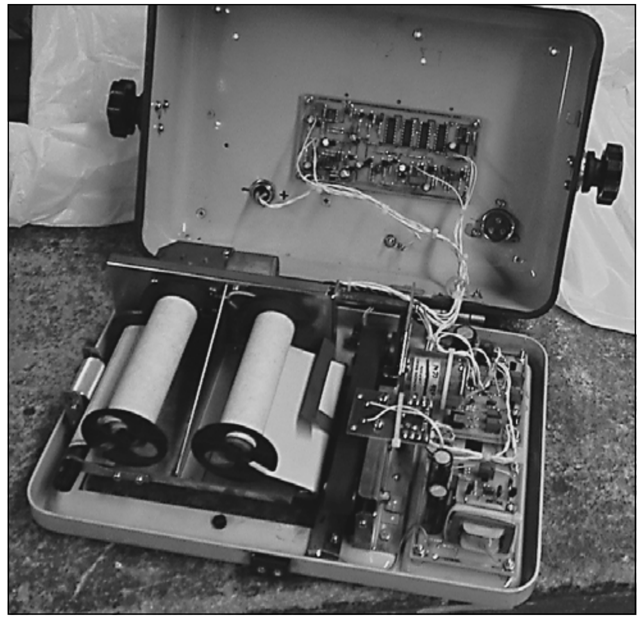
The display unit for the sonar system is a modified fish finder. Numerous models of the graph paper type fish-finders have been manufactured over the years. They range widely in quality and complexity from cheap junk, to really nice high quality units. At this point in history, the LCD display has completely replaced the paper units. The old mechanical units are all available now, for virtually nothing, on eBay and other used equipment sources. This is good for the sonar maker. I searched eBay for possible models to use for my sonar and settled on Si-Tex model HE-32 as the best and Si-Tex model HE-31 as next



Prototype modified Si-Tex HE-32 graph fish finder

best. I looked for a high quality unit that is easy to work on and not so rare that it cannot be readily replaced.

Can you build your own display? It would take a first class machinist to make a paper transport as nice as the Si-Tex units. The do-it-yourself credo encourages using available surplus equipment, especially when it is cheap



New circuit cards installed in the Si-Tex unit

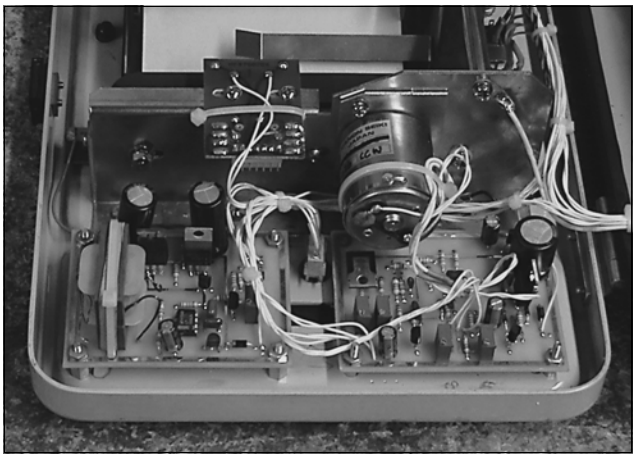
and readily available. I decided to concentrate effort on the transducer and electronics and utilize the Si-Tex paper transport with improved electronics.

Si-Tex uses 4 inch /100 mm paper which seems to be the most often used size on all brands of fish-finders. I have bought many rolls of paper on eBay. Different manufacturers use slightly different rolls, but the paper seems to be essentially the same. If you can't find the genuine Si-Tex paper, any other type

Many types of recording paper will work.

can be transferred to a Si-Tex roll. There might be some differences in the writing voltage necessary with different paper types, but it is easy to compensate with circuit adjustments. On eBay search: “graph paper” or “recording paper”

Several factors determine the maximum useful range of the sonar system. The power and sensitivity of the electronics and the timing of the stylus sweep are the main factors



Stylus driver board (left) and motor drive board (right)

within our control. Assuming that the sonar signal is powerful enough, it still takes appreciable time for the signal to reach a distant point and return. This returning signal is what we want to print on the paper. The round trip range in water is about 40.8 ms for each 100 feet. A range of 2500 feet requires one full second for the sound to return.

The Si-Tex model HE-32 incorporates a gear drive from the motor to the stylus belt. This is preferred because it cannot slip and doesn’t deteriorate. The gear ratio is such that a sonar range of 1500 feet is practical. The limiting factor on long display range is the slow rate that the stylus must move across the paper. The motor and drive circuit becomes unstable at very slow speeds. If the original fathometer was designed for deep depth ranges, it will be close to the appropriate ratio necessary for long sonar ranges.

The Si-Tex model HE-31 uses a pulley system with rubber belts for driving the stylus belt. This leaves open the possibility of changing the ratio by replacing the pulley. I didn’t use the HE-31 for my sonar, but if you want really long ranges, this is the one to use. You can have pulleys made by a machinist for any ratio.

I provided for two range settings in the circuit card design, but any number of ranges can be implemented. It requires a trim-pot for each range and a multi-position switch.

For short ranges the opposite situation exists. The motor must turn fast. A 500 foot range is good for close-in work. You can estimate distance to the precision necessary for diving purposes, with the range lines at 100 foot intervals, on a 500 foot range.

The sonar is much more useful with a calibrated display. Possible methods include: preprinted paper with range lines on it, a transparent gauge over the paper, or an electronic system to print lines on the paper. I chose the electronic method.

The calibration system is contained on a circuit card and should be mounted within the display unit. The range mark system is a precision timer that is synchronized each time the stylus begins its sweep across the paper. It then prints a number of dots on the paper at a spacing of 40.8 ms, which represents 100 feet of range. As the paper moves the dots combine to draw horizontal lines 100 feet apart. This system has the advantage of being accurate

regardless of the motor speed. If the motor is adjusted for a slower speed, for example, more lines will appear, always representing 100 feet of range.

The distance mark system is a precision timer that prints a series of dots through one sweep of the stylus. This forms a vertical line on the paper. The timer then waits for the required time before enabling the next line to be drawn. The time intervals are 59.2 seconds and 14.8 seconds. A chart of boat speed vs. timing is used to give value to the line intervals. For example: the 59 second timing will draw lines at 100 foot intervals when the boat speed is one knot. The result is a grid of known dimensions drawn on the paper which is true in real time. The stylus motor will not affect the range accuracy and the paper speed will not affect the interval of the distance traveled lines. In practice if the boat speed is held steady with a GPS the distance lines will be a true representation of travel across the bottom. If the line of search is between known GPS waypoints, the grid lines allow calculation of the position of objects. As divers, this is what we want!

An issue for experimentation is the delay between the finish of a sweep and the start of the next sweep. It takes the same amount of time to bring the stylus back to the top as it takes to sweep the paper. This is dead time in your search. With really long ranges, this becomes frustrating.

One mechanical solution exists. You can add a second stylus to the belt so that it begins a sweep just after the first stylus finishes. The difficulty is aligning the two styli to exactly trace the same path across the paper. The stylus belt is rubber and may wander a little on the rollers. This might cause an uneven looking printing on the paper.

Another problem is triggering the transmitter for the second sweep. A second reed switch can be added in the correct position to trigger the transmitter when the magnet sweeps by. The adjustment will be critical. If not correct, the two images written by the two styli will not perfectly overlay.

An entirely electronic solution involves accelerating the motor during the time when the stylus is returning to the top. This requires some additional circuitry. A time delay could switch the motor to a higher speed at the end of each sweep, hold the faster speed for a period of time, then return to normal speed before the stylus reaches the beginning of the next sweep. I like this method and will probably incorporate it in my own unit in the future. It requires no mechanical changes to the motor drive.

What about recorders with larger paper? They do exist, but I didn't find very many available. They are professional models used on larger ships and may still be in service in the fishing industry. Another problem is the power supply. Some of these very large units have AC motors which will not work for this system.

Other recorders used in the medical and scientific fields may be adaptable for the sonar display, but I didn't really look in that direction. The typical fish-finder units are by far the easiest to find and cheapest.

Some fish-finders have a circular stylus path. This usually indicates a lower quality unit. This design avoids the belt and rollers necessary to sweep in a straight line across the paper. A rotating disc holds the stylus and

sweeps across the paper in a semi-circular path. It works for its original purpose, looking at the bottom contour, but is not really useful for a sonar display. The display is highly distorted by the semi-circular tracing path.

I like the two Si-Tex models mentioned above, but two other units stood out as being very good candidates for sonar usage. These two seemed to be equal in quality with the Si-Tex units and easy to modify.

Lowrance model LRG 1510B Truline Recorder. This is a very nice unit and equal to the Si-Tex in quality. The interior is all stainless steel construction with a heavy duty case. The motor is compatible with the circuitry described in these plans.

Humminbird model CH 1000A. This is another high quality unit. It has extensive waterproofing of the case with rubber seals everywhere. The motor has a toothed wheel with a photo-cell light interrupt feedback system. It can be adapted to the motor control circuit card with some minor circuit changes.

This is not a comprehensive survey but only a random look at units that I happened to buy. There are probably other units equally useful out there waiting to be found. In general, choose a unit that is worth the effort. The cheaper units will not give satisfactory results.

Try to buy a few identical units so you will have plenty of spare parts. The rubber stylus belt should be supple and not cracked from age. If the belt is too stiff, it will not give consistent speed when moving on the rollers. Combine the best parts from your units and keep the rest for spares.

If you plan on using the circuit cards described in these plans, you will need to remove all the original electronics from your unit. This is really the easiest way to go and the surest rout to success. Leave only the paper transport mechanism, the stylus drive motor and the paper drive motor. The connection to the stylus will be a single wire connected to an insulated wiper strip. These components will be connected to your newly built electronics.

The location of the new switches can now be planned. The Si-Tex units have numerous controls on the front and the new switches can fill these holes. For a first class appearance, an overlay can be made to cover the unused holes and label the new switches. The power input connector can be retained and used.

There will be two connections to the receiver-transmitter electronic unit. You can use any type of connector, but the cables should be shielded. I used two BNC jacks and two coax patch cords. During testing, these BNC cables are compatible with common test equipment, making it easy to connect items together.

The three circuit boards are sized to fit well in the Si-Tex units. Be careful about grounding. Bond the movable door section to the back case with a #18 wire. Mount the circuit cards on metal standoffs so they are electrically grounded to the metal. Noise from the stylus current can interfere with the other circuitry if grounding is not correct.

Symptoms of noise problems include: inconsistent motor speed, smearing of range lines, triggering problems, and interaction between printing and motor speed. Avoid these problems by good electronic assembly techniques. The receiver is sensitive to micro-volt level noise signals which can be fed back from the stylus writing circuit card via the connecting cables. To avoid this, proper grounding is necessary.

If you are using a unit with a plastic case, install a metal ground plane inside the case to mount the circuit cards on. Hobby shops sell thin brass sheets which are nice for this purpose. Bond the metal sheets to the metal parts of the unit including the motor frame.

The display is a stand alone unit and can be built and tested without the receiver-transmitter unit. When it is powered up, it will print the range lines and distance lines on the paper. A dc pulse, applied to the input jack, will print a mark on the paper.

The circuit card placement in the Si-Tex unit is visible in pictures of the prototype. The main issue is the placement of the stylus driver circuit card. It should be near the point where the stylus wire is connected. The worse case would be to mount it far away on the back of the case. The noise from the high voltage lead routed near the other cards will cause difficulty.

Finish the display and completely check it out before trying to operate the whole system. I was fooled a few times by problems with the system that seemed to be caused by the receiver. When I straightened out the display noise problems, the receiver turned out to be fine.

The Electronics

This sonar system consists of a transducer, a display device, and electronics to process the signal between these two components. The electronics accomplishes the following tasks:

- Create a trigger pulse
- Generate the transmit pulse timing
- Generate a short 24 KHz pulse
- Amplify the pulse to the desired level
- Drive the transducer with the correct impedance match
- Selectively amplify the received signals
- Tailor the gain of the receiver
- Demodulate the received signal
- Drive the display system with the correct level.
- Control the stylus and paper motors
- Generate the stylus writing voltage
- Generate calibrated range and time marks

The circuitry presented here is not an attempt at state-of-the-art design. It consists of well proven circuits which have been used in equipment for decades. I have combined these circuits to create a useful unit which is easy to duplicate. This type of circuitry can be understood by persons with a background in electronics, even if their training was years ago. If you don’t have this background, I assume that you can find a friend who can help with the electronics. A local Amateur Radio operator can probably introduce you to some electronics enthusiasts.

The operating frequency is determined by the transducer. The type of drivers used in this sonar must operate near their resonant frequency for good efficiency. The nominal frequency is 26 KHz and is exactly determined during tests after the fish is built. The transmit oscillator generates a stable, constant frequency which is modulated into pulses and amplified by the power amplifier. The output of the power amplifier is coupled through a transformer and a fixed inductor to the transducer.

The receiver section is a tuned amplifier which responds to the operating frequency. The frequency can be tuned across a limited

band using two DIP switches on the receiver board. The bandwidth is optimized to allow good pulse response and non critical tuning, but to reject off-frequency noise. The receiver has a log-response detector which expands the dynamic range between the lightest and darkest marking on the graph paper. A time-based automatic gain control circuit is included to tailor the receiver gain response. This is adjusted during operation to eliminate overload from strong short range signals and allow maximum gain for longer range signals. The log detector and time-based gain control circuit provides proportional response on the graph paper from short to long range. A manual gain control sets the overall amplification.

The modified paper transport requires circuitry to control the motors and establish calibration. The stylus motor drives the belt, which sweeps the stylus across the paper, through a step-down gear. A feedback servo system is used to establish the motor speed for different ranges. The motor has a rate generator built in which generates a frequency proportional to the speed. The motor control circuit measures this frequency, compares it to a programmed voltage, and applies the correct drive voltage to the motor to maintain the speed. Two range settings are available.

The paper speed control circuit is a variable voltage regulator which sets the appropriate paper speed. The paper speed is not as critical as the stylus speed and does not require a feedback system. Two paper speeds are provided. Different ranges require different paper speeds.

The calibration circuitry generates the range and time marks. The range marks are short dots that print on the paper at 100 foot range intervals during each stylus sweep. They are synchronized with the transmit trigger and draw horizontal lines on the paper as it moves to the left. When targets are printed on the paper, it is easy to compare the targets to the range marks and estimate the actual range to the target. This is more accurate than a physical scale because it does not depend on the stability of the stylus motor speed. The range marks are generated by a precision timer circuit and are quite stable.

The distance marks are vertical series of dots that print on the paper periodically to indicate forward distance traveled by the fish. This is simply a precision timer which establishes a number of seconds between marks. A chart is used to relate the boat speed in knots to the distance mark intervals in feet. When the boat speed is derived from a GPS, the distance marks on the paper will be quite accurate.

The two calibration markings on the paper create a grid of known dimensions. The size and relative position of features on the bottom can be readily visualized. The methods of determining the exact location of objects is discussed in another section.

The stylus drive circuit is a variable high voltage source which is modulated by the received signal. The stylus drive is not the amplified received signal, which would cause feedback through the receiver, but a separate frequency, modulated by the received signal. This high voltage signal burns through to white surface of the paper and exposes the black carbonized layer.

An auxiliary circuit receives the pulse from a magnetic reed switch and generates a clean trigger pulse. When the stylus belt passes the

correct point, at which the stylus begins to travel across the paper, a magnet closes the reed switch for a brief period. The trigger pulse synchronizes the transmitter, receiver gain circuits, and the calibration range marks.

The power supplies generate the operating voltages for the individual circuit cards. Each circuit card has one or more voltage regulator circuits to ensure good isolation between circuits.

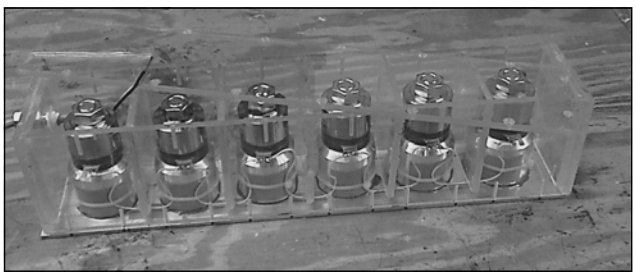
The circuitry is organized on five circuit cards. This allows changes and modifications to be carried out on a section of the system without affecting the entire unit. The three circuit boards that concern the paper drive, stylus, and calibration system have independent power supplies. They can be installed in the fish finder original enclosure and operate remotely from the transmitter and receiver unit. The power source is supplied to the display unit and the receiver-transmitter enclosure separately. Two shielded cables are needed to carry the trigger and receiver signals between the units.

The transmitter and receiver system is comprised of two boards which are interconnected. They must be located together. The power supply for both boards is contained on the transmitter board. The input-output connection to the transducer goes to the transmitter board.

Building and Testing

Building the Transducer

The transducer is a fabricated assembly consisting of an aluminum plate, six driver units, and a lexan enclosure. The assembly is a waterproof box with the drivers inside attached to the sound plate.

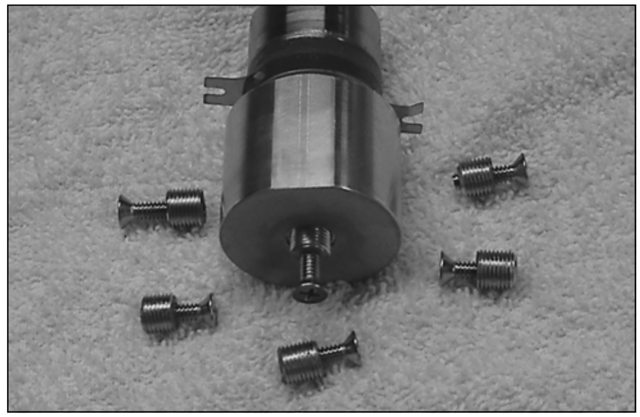


Lexan enclosure

Start with six tested and matched driver units and a plate cut to the specified dimensions. The drivers will be uniformly spaced on the plate with enough space for a lexan bulkhead between each driver. The driver spacing is roughly one wavelength center-to-center, or about 2.2 inches.

The drivers are secured to the plate with #10 flathead screws. The mounting hole in the drivers is a large tapped hole. Inserts must be fabricated to accept the #10 screws and threaded into the mounting holes. The inserts are created by drilling and tapping a bolt of the right size and cutting it into sections.

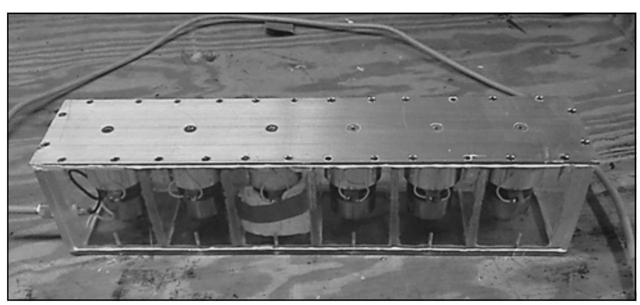
After the six holes are drilled and counter bored in the aluminum plate, the drivers can



Inserts are tapped for #10 flathead screws

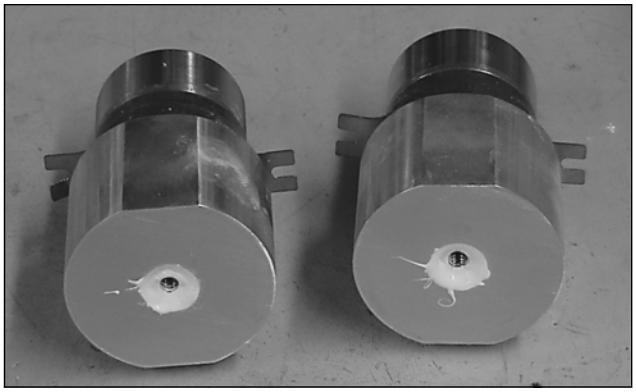
be mounted. The driver mounting hole must be well sealed to prevent water intrusion into the interior of the driver. The following operation is done in one quick session to prevent the glue from beginning to set up before the unit is assembled. Be sure everything fits before starting.

Coat the inserts and the inside threads of the drivers with marine sealant and install the inserts in the drivers. Coat the screws and the # 10 tapped holes in the inserts already in-

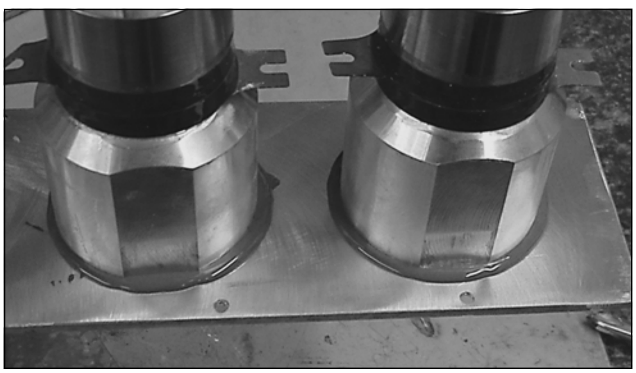


The sound plate is screwed to the lexan box

stalled in the drivers. The drivers must be rigidly bonded to the aluminum plate with epoxy glue. I used JB Weld, a metal filled epoxy. Coat the bottom of the drivers and the footprint of the drivers on the aluminum plate with



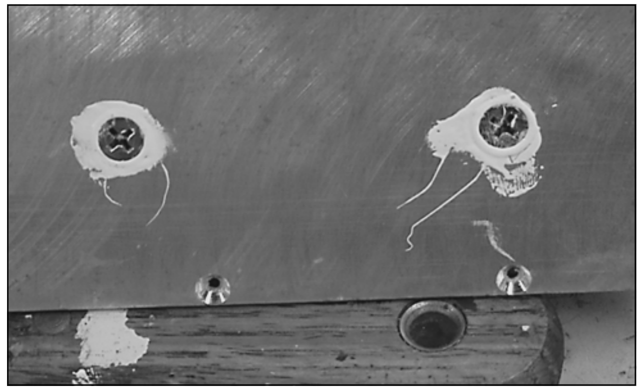
Carefully seal the mounting screw holes



The drivers must be bonded to the sound plate with epoxy

the epoxy. Sand and clean the aluminum plate to ensure a good bond.

When all the pieces are ready, tighten the drivers in place using the # 10 screws. The epoxy should squeeze out between the driver and the aluminum plate. The drivers should be placed in the same orientation and all tightened down flush with the aluminum plate. Some sealant should squeeze out under the flat head screw indicating a good seal.

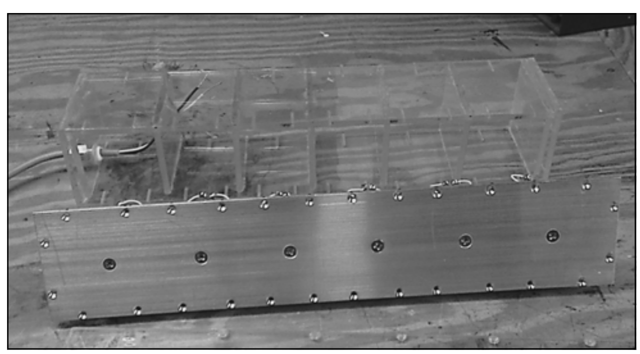


The screws must be well sealed

In some of the illustrations, the small counter bored holes, around the perimeter, are shown already drilled in the aluminum plate. Do not drill these holes until the plans call for them to be drilled. The pictures were not taken in the exact sequence of easiest construction.

The drivers are all wired in parallel and the hot-side wire is protected from the body of the driver and the metal plate with a bit of insulating tape. The ground side is electrically connected to the aluminum plate, but a wire is run to each driver anyway. The wired drivers are visible in some of the illustrations. The cable, which extends through the waterproof stuffing box, is not connected until the box is ready to be glued in place.

The lexan box is constructed with the general layout visible in the illustrations. Make the lexan box slightly narrower than the di-



Screw holes are spaced about 1 inch apart

Bulkheads, wiring and sealed cover plate are visible

mensions of the plate. This allows the screw holes to be slightly back from the edge of the sound plate. Calculate the dimensions of the bulkheads and end pieces. The dimensions will depend on the thickness of the lexan material that you use. Cut 5 bulkheads and 2 sets of end pieces. The bulkheads do not quite reach the aluminum plate but do contact the lexan lid. The bulkhead extends to within about ¼ of an inch of the aluminum plate. The end pieces reach both the aluminum plate and the lexan lid. Cut the sides to the necessary dimensions and assemble the box. The lexan glue sets too fast to assemble the entire box at once. Start by gluing the bulkheads to one side piece and when it is set, glue the other side in place. Maintain the square shape as much as possible. Finish by gluing the end pieces in place.

At this point you have a box which fits over the drivers and seats down on the aluminum plate. It should be square with the plate, and the top surface should be flat enough to accept the lexan lid. The bulkheads do not touch the aluminum plate. The ends are a double thickness. Use a file to make the box top and bottom as flat and true as possible. You want a good fit to lessen the amount of sealant required to fill the gaps.

The holes for the # 4 screws are drilled to match the lexan box. It is easier to drill the holes to match the box rather than build the box to match holes already drilled. Trace the footprint of the box on the aluminum and use a small punch to locate the position of the holes around the aluminum perimeter. The interval between screws is about 1 in. Drill the aluminum with a small drill bit to define the position of the holes. Install the lexan box in position on the plate and secure the assembly with tape so it doesn’t move. Turn the box over, with the plate side up, and with the same bit, slightly drill into the lexan through each existing hole. These holes should be drilled deep enough to definitely transfer the position of each hole in the lexan. When all the holes are marked, inspect the lexan to be sure none of the holes are too close to the edge. If they are, you may be able to “move” the hole slightly since we are working with a tiny bit at this point.

Drilling the lexan is problematic and it is better to practice with scrap pieces first to determine the right technique. The drill size must match the screws that will be used. Practice with some scrap pieces to get the right combination of screws and drill size. Do not force the screws into a too small hole. It is better to use a longer screw with a lighter fit than a shorter screw with a tight fit. High quality screws from a marine store work best because they have sharp threads and no burrs.

When the holes are positioned on the lexan box, they should be drilled on a drill press to

insure that they are square with the box. Drill the holes somewhat deeper than the screw length to accommodate the sealant which will be carried into the holes ahead of the screws. Drill the aluminum plate and counter bore the holes for the flat head screws. You want an easy fit so there will be no bind when the screws are installed. Assemble the plate and box together without sealant and tighten all the screws to be sure that it will fit. There should be ample depth for the screws. Check that the screws will all be flush with the aluminum when tightened. There should be virtually no gap in the junction between the metal and the lexan.

After testing the fit, remove the screws and separate the aluminum plate from the box. Fitting the lid is the same procedure as fitting the aluminum plate except that the holes can be sighted visually looking through the transparent lid. Tape the lid in place, and drill the locating holes with the small bit through the lid and into the lexan box. After all the holes are defined, the lid can be drilled with the necessary size bit and counter bored to accept the flat head screws. The lexan box can then be drilled on the drill press. Remember to allow plenty of depth for the screws and sealant. The lid should be sized so that it overhangs slightly to make it easier to drill the holes and lessen the chance of the lexan cracking around one of the screw holes. The lid should be test fitted and all the screws tightened to verify the fit and reveal any gaps. The lid can flex somewhat, to compensate for imperfect fit, unlike the aluminum plate.

The cable is not critical electrically but is problematic when trying to seal it against water intrusion. The round style cable is easiest to seal using a stuffing box fitting, but other types of cable could work. The cable should be very sturdy with thick plastic or vinyl insulation. Any cable with a rubber jacket will not stand up. Some cable has paper strings inside with the conductors to take up the void and keep the round shape. This makes the cable soft and the compression fitting cannot develop enough pressure to seal without crushing the cable. It also can allow water to wick through the cable and through the stuffing box fitting. Look for cable that has solid plastic insulation, which is molded around the conductors, with no extra filler strings inside. If you look at computer power line cords at a junk store, you will find a suitable cable to use. Pick one that is very stiff and not too big in diameter. For some reason this type of cable is often grey in color.

The waterproof stuffing box is fabricated from a ¼ in. brass compression fitting. These are normally used with copper tubing. Remove the copper insert and ream or drill the passage through the body of the fitting to accommodate the round cable. The cable is likely to be slightly larger than the existing passage in the fitting. The cap may need slight reaming also. The purpose of the fitting is to clamp down on a rubber washer and squeeze the cable and make it impossible for water to leak past. The cap captures the washer and compresses it against the body of the fitting.

The body of the fitting is glued into the end of the transducer lexan box. If the hole is sized just right, the fitting will thread into the lexan. Don’t create too much stress and crack the lexan by forcing it into a too small hole. The end of the lexan box is a double thickness of lexan and makes a sturdy location for the fit-

ting. Locate the fitting toward one side of the lexan box and about halfway between the lid and the aluminum plate. Check that the cable will clear the driver in the chosen location. The fitting is visible in some of the illustrations.

Glue the body of the compression fitting into the lexan box using the marine sealant. When the sealant is dry, insert the cable and select a suitable rubber washer. I used a rubber grommet with a ¼ inch inside hole. It must be trimmed around the outside to fit in the cap but the inside hole is just right. Coat the cable and rubber washer with sealant and tighten the cap. It doesn't take much pressure, if the washer is the right size. When the cable is tight in the grip of the washer, the pressure is correct.

Verify the wiring of the drivers and solder two conductors of the cable to the driver nearest the cable entry point. The third conductor is not used. Now, the transducer can be closed and sealed using the marine sealant. Some desiccant should be enclosed in the transducer to prevent moisture from condensing inside. I used the type available at craft stores for drying flowers. It is a sand-like material which can be wrapped in a paper packet and taped inside. Visually check for any possible water leaks where the end pieces are glued on the lexan box.

Sandpaper the edges of the lexan and the aluminum and clean the mating surfaces with lacquer thinner. Apply ample amounts of sealant and assemble the transducer. Only moderate screw tightness is necessary. Do not crack the lexan at this point!

Building the Fish

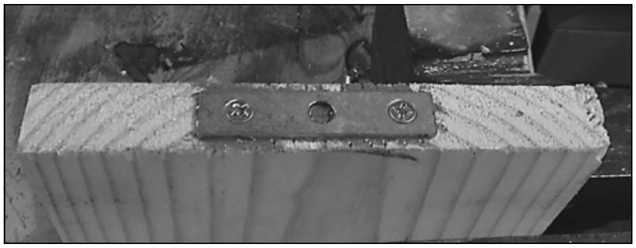
The fish is assembled from 7 pieces of pine, one-by-six, lumber. The dimensions of the pieces are detailed in the specifications. Select the pieces to be used and cut the slots in each board. Be sure to make the cuts accurately so the resulting assembly won't need too much trimming inside the slot.

Choose the best seven pieces

Cut a slot in each of the pieces as illustrated. The pine wood is very soft and easy to work with, if it is fresh. Try to use wood all from the same batch so it will have uniform moisture content. You don't want uneven shrinkage once the boards are bonded together. After the fish is finished, you must be careful about leaving it in the hot sun for the same reason. Once it is painted it will be more stable.

Select one board to be the master piece and install a pivot plate on each end. I used a typical hardware bracket. The purpose of the pivot is to define the center of the fish during the shaping process. This assumes that you will not have access to a proper wood lathe. If you

are using a wood lathe, you must define the centers at this point but you don't need the plate. Measure and place the centers in relation to the slot. The centers need to be accurately placed so the finished fish will have the



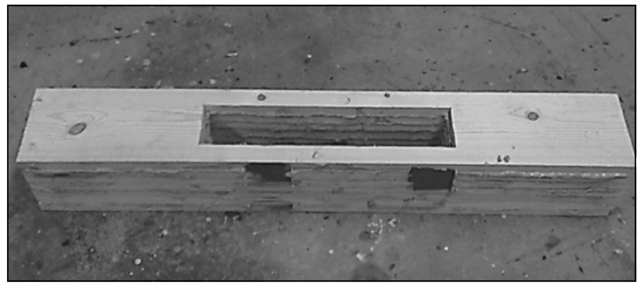
Pivot point is reinforced with a bracket

slot in the geometric center after turning. A clean ¼ inch hole is drilled in the brackets and they are glued and screwed to the wood. The pivot plates will be removed when the shaping is finished.

Stack the wood pieces with the master piece in the center and test the alignment by clamping the sides of the slots together with scrap wood pieces. The slot needs to be accurate for best results, so now is the best time to trim as necessary. Practice with the clamps to be sure everything will fit.

Now comes the messy part! It is a good idea to experiment with the glue on some scrap pieces to learn the best thickness of application. You want total coverage with no air gaps. You have to work quickly because the glue forms a skin very quickly and eventually will not squeeze out easily when clamped. Spread the glue on all surfaces of the wood and work it in to all the cracks and pours. The scrap

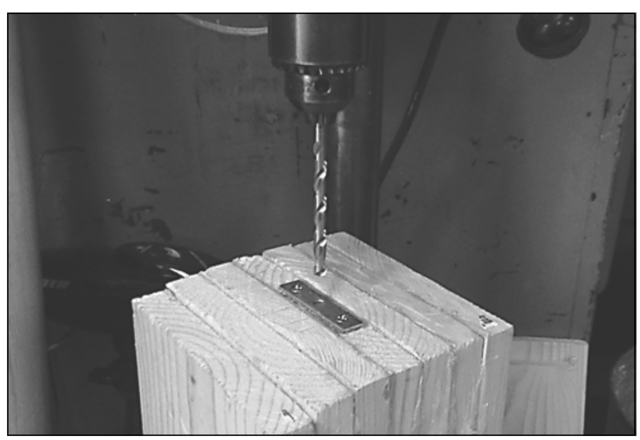
The slot must be aligned accurately



Ready to begin carving

pieces that are used to line up the slot should be covered with paint masking tape so they can be removed after the glue dries. Clamp it all together until the glue squeezes out of the joints. When it is dried, you will have a solid block with the slot through the center.

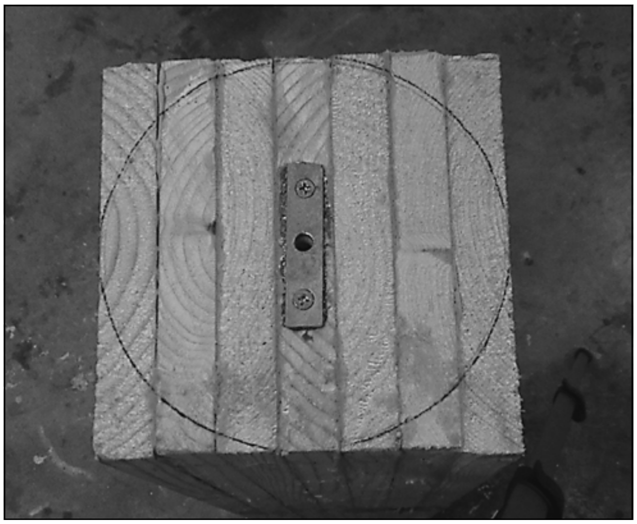
The centers are drilled into the wood, accurately, with a ¼ inch drill, about 1 inch deep. This allows the pivot pin to extend into the wood and securely hold the wood block during the shaping operation. The hole in the bracket is already there, of course. At this point, the



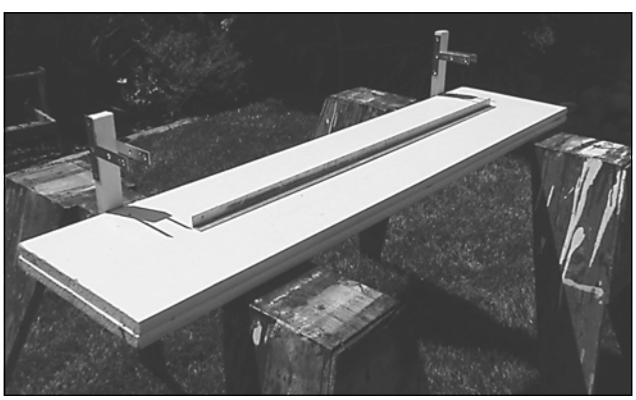
Drilling the pivot holes

wood block should be solid and straight with the pivot points in the geometric center in relation to the slot. An illustration shows a circle drawn on the end of the block representing the material that will be removed during the first shaping cuts.

If you have access to professional wood working equipment, the shaping process will be easy. I assume that the majority of builders will have only common, basic, woodworking tools. The following section details one way to do the shaping but not necessarily the only way.



The first cut will make it round

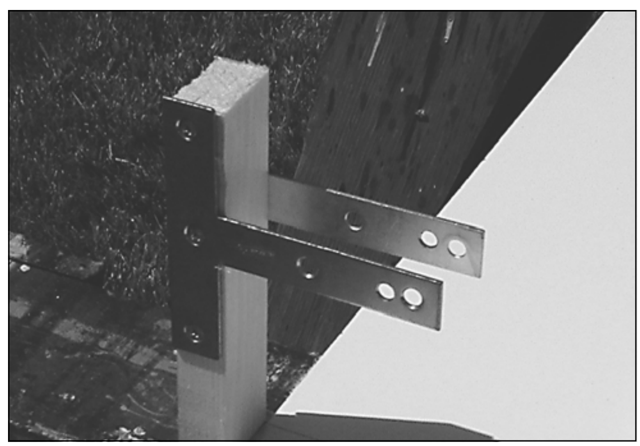


The jig for shaping the fish

Construct a base and uprights to hold the laminated wood and allow it to be rotated on the pivot points. I used a pre-made shelf board with a smooth plastic finish. Cut the shelf board in half and glue it together to double the thickness and make it very rigid. The plastic finish makes the surface smooth and allows the router base to slide around easily.

The uprights are glued securely to the boards and spaced so that when the wood is held in place, it will rotate freely, but have little play end-to-end. The pivot pins are held in place by two hardware brackets on each end. Two brackets are used at each end to maintain the pins in a horizontal position and not allow the pins to droop from the weight of the wood. Drill a clean ¼ inch hole in each bracket and align the brackets carefully so the ¼ inch holes are all in line and equal height above the base. Two ¼ inch bolts are used as pins and should extend into the wood about one inch.

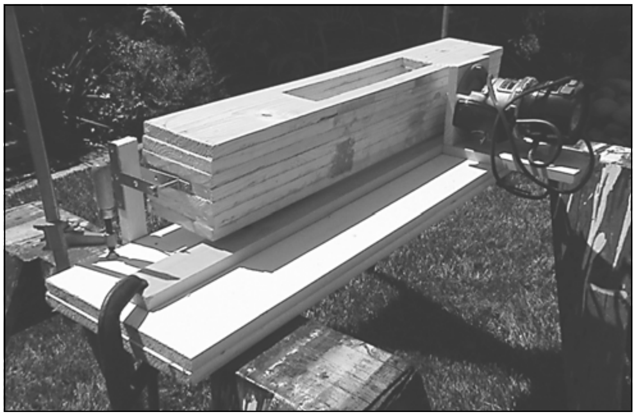
Construct a jig for the router that will slide around easily, on the base, and hold the cutting blade at the same height as the pivots. The design of this jig depends on the type of router to be used, but it should be sturdy, and allow ac-



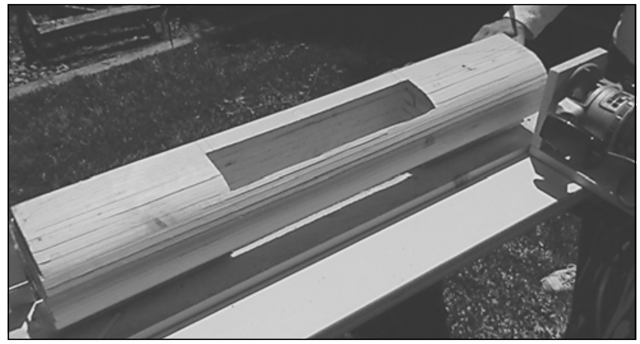
End support

cess to the router controls. A fast cutting router bit is used to remove material quickly.

A straight piece of wood is clamped to the base to serve as a guide. Get ready for a messy and noisy operation! This goes much easier with a willing helper to turn and hold the work piece. For the first shaping cut, the guide is adjusted so that the router blade will just reach the flat side of the laminated wood. With this setup, after all the cutting is finished, the laminated wood will be round. The router is moved back and forth to cut material and the wood is held in place for each sweep. This is the rough cut and need not be really smooth.



The router in position to shape the fish

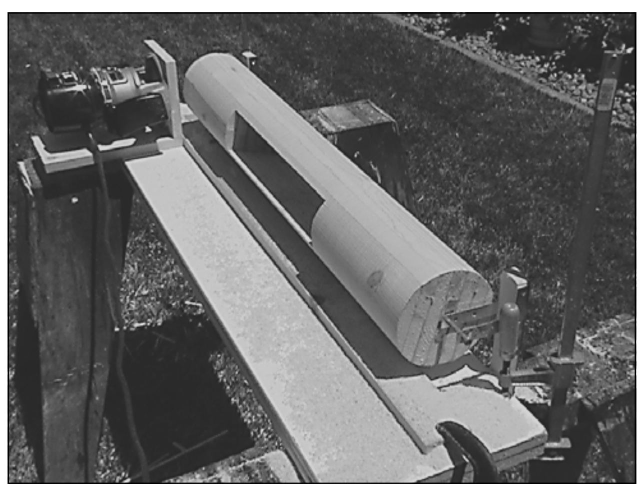


A quick cutting router blade does the job

When this first shaping cut is finished, the wood should be round with uniform diameter all along its length. If the pivots and slot were laid out accurately, the slot should be very close to symmetrical alignment with the laminations in the wood and the sides should be equal thickness.

The first cut leaves the wood much larger in diameter than the final dimension will be, but is useful to allow corrections in the dimensions. With the finished transducer, do some careful measuring, and begin fitting it into the slot. There should be an easy clearance all around with no binds. Be sure to allow space for the hardened squeezed out glue on the edges of the transducer. There has to be space

A willing helper is greatly appreciated

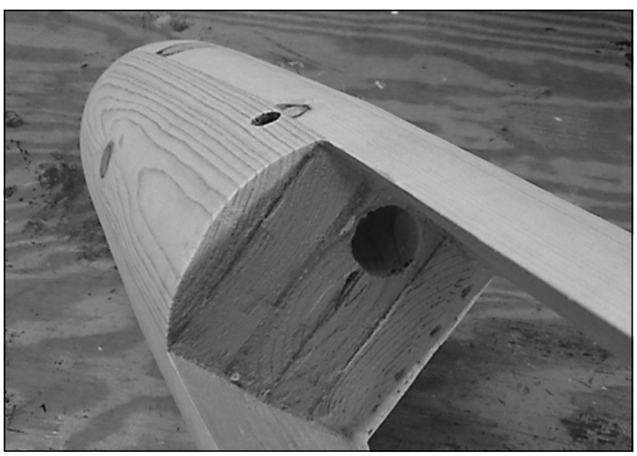


The first cut is complete

for free water flow around the transducer so it will not retain water and fail to drain out.

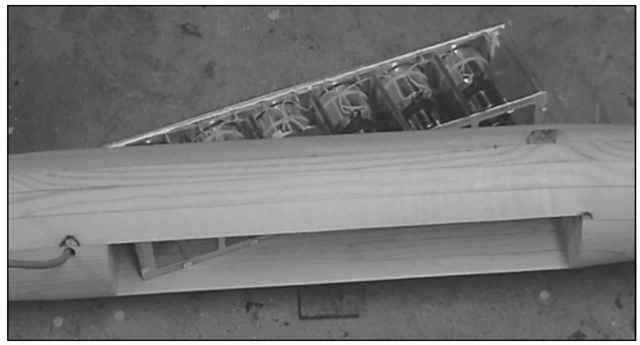
When the transducer fits correctly, calculate the necessary diameter for the finished fish. The sound plate will be flush with the side edges of the slot and the back lexan surface will be somewhat recessed from the same edges on the other side. The exact diameter is not critical because the wood cowling will be shaped to fill in the back side and cover the lexan after the transducer is installed. The height of the transducer is somewhat less than the inside depth of the slot and the transducer is offset towards the sound plate side and not centered on the axis of the fish.

When the correct dimension is known, more shaping can be done. Cut the wood to the final diameter, while being careful to make a smooth surface. Don't cut the nose or tail shape at this time. The transducer should be fitted first before deciding which is the nose and tail.



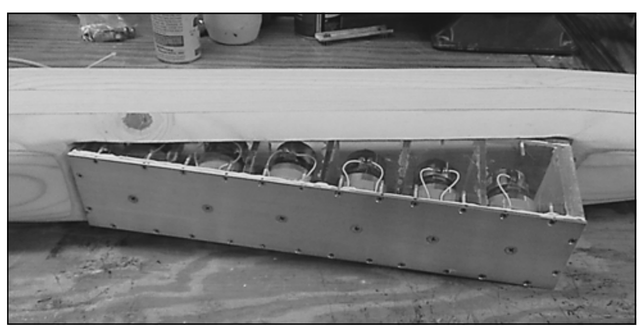
The hole for the wire and stuffing box

A difficult issue is the electric cable to the transducer. The transducer can't slide directly into the slot because the waterproof stuffing box protrudes from the end. Carefully measure the position and drill a hole in one end of the slot to accept the waterproof stuffing box and cable. The hole is positioned to allow the sound plate to align with the sides of the slot. There are four choices for the position of this hole, but after it is drilled, the front and top of the fish is defined. Another smaller hole is drilled from the top surface of the fish into the bigger hole to allow the cable to emerge. Sand the interior of the holes smooth so it will be easy to seal the wood with paint.



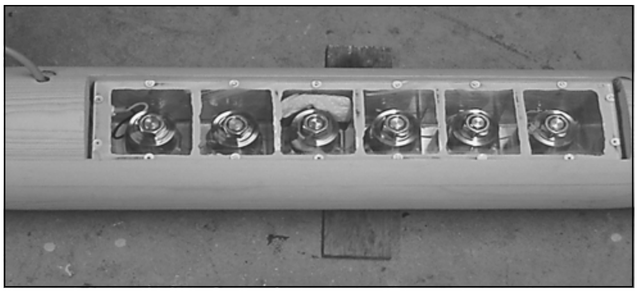
The transducer tilts into position

The transducer is installed by tilting it into the slot while feeding the cable out through the hole. A bevel must cut on the front wall of the slot opposite where the cable comes out to allow the transducer to enter the slot at an angle. This bevel will be filled with glue when the transducer is finally secured in place. The transducer sound plate should align with the



A bevel on the front wall of the slot is necessary

sides of the slot and the waterproof stuffing box should not bind in the hole but have ample clearance. There is free water access to the hole and no sealant should be added. If the cable is glued into the hole, it will be impossible to remove the transducer without major effort.



The transducer in position

The sound plate alignment is the most important issue since we want smooth water flow with minimal turbulence. With the sound plate aligned with the sides of the slot the front and back walls of the slot extend above the surface of the plate. These are contoured to meet the surface of the sound plate at the front and back. The sharp sides of the slot are smoothed off and shaped to join the contoured ends. A slight bevel is cut around the sides of the slot next to the sound plate to allow easy gluing.

When the transducer fitting is finished, set the transducer aside, and the final shaping of the nose and tail can be done. Don't forget which end is the nose! The cable entry will be toward the front and the sound plate should be on the right hand side. The shaping can be done with smaller pieces of wood used as guides, clamped to the base. You can do it freehand, but it is a lot safer to use a guide! Move the guide for each little section. You want a classic torpedo shape with a round nose. The tail must not be too slender because there must be enough structure to screw the fins into.

When the shaping is finished, reconfirm that the transducer fits properly and adjust the clearance as necessary. There must be an easy fit with room for the glue on all sides. Now, the fish should be painted. I used oil based paint and thinned it for the first few coats, so it would penetrate and seal the wood. Be sure that the wood is well sealed, especially in the slot and cable hole. The interior of the slot and the cable hole cannot be painted again without removing the transducer. When the paint is dry, the fins can be fitted and attached.

The fins are cut from un-galvanized sheet steel. As mentioned earlier, steel is easy to

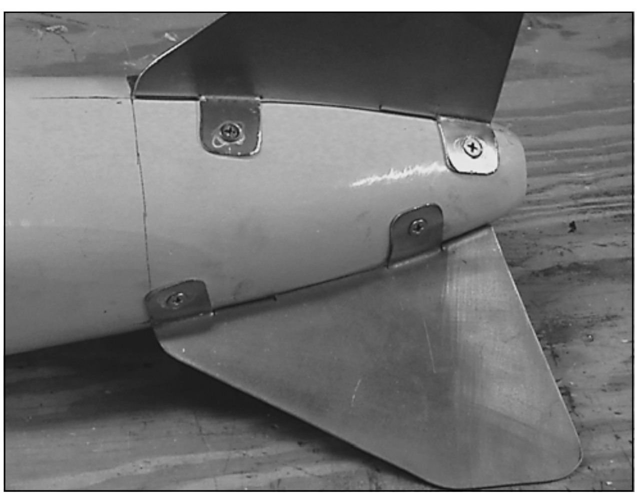
The fins are cut from .060" steel

work, bend, and shape and also easy to repair if it gets damaged during usage. First lay out the three for and aft lines where the fins will be mounted. This should be very accurate so there is no rolling or steering moment applied to the fish when it travels through the water. One fin should be vertical on the top of the fish. This allows the fish to sit upright when

Be sure the alignment is correct

placed on the deck of a boat and be easily picked up by grabbing the bridal. The other two fins are positioned 120 degrees apart. The shape is not critical but you don't want sharp corners.

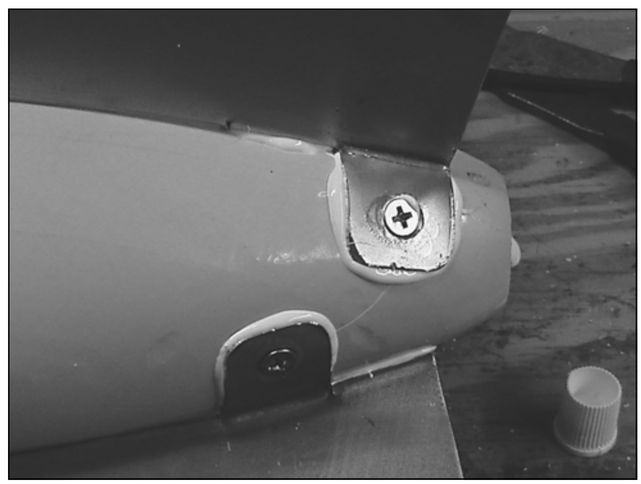
First cut out the shape of the fin using cardboard and be careful to match the contour of the line where the fin will be attached. Then trace the cardboard three times on the steel sheet and add the tabs. Cut out the steel fins and smooth the edges. The tabs are about one



The tabs are shaped and screwed into position

square inch and are bent along the contour line in a staggered pattern. The tabs are first drilled and counter bored, for flat head wood screws, then bent and shaped to fit the wood surface. The fins should be all very similar, but each one is fitted to its own position.

The screws are temporarily installed one at a time and the tabs are tapped into shape with a small hammer and punch until the screw can be tightened all the way down. There should be no space under the tabs and they should follow the curvature of the fish. For a more pleasing appearance, the tabs can be inset into the wood so they are hardly visible. This was not done on the pictured unit. When the tabs



Sealant should fill the space under the tabs

are shaped for the best possible fit, remove the fins and apply sealant to the tabs and the fish surface where the tabs will be seated. The high quality marine sealant should be used here. It will prevent water from getting under the tabs and rusting the metal. When the screws are tightened, the sealant will squeeze out, indicating complete filling of the area under the tabs. With this construction, the fins are very robust. After the fins are installed and the sealant

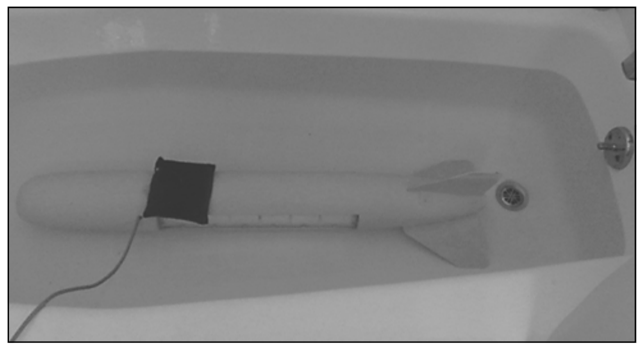
is dry, they can be painted. Several coats should be applied to help slow down rust.

The transducer is glued into the fish in two steps. The fish is placed with the sound plate down and the fish and transducer resting on two pieces of scrap wood. The wood pieces will insure that the sound plate is flush with the edges of the slot on the sound plate side. Be sure that the transducer is correctly positioned, in the center of the slot side-to-side, and the cable is freely passing through the hole. Apply glue to both ends of the transducer, at the fore and aft walls of the slot, on the lexan side. This will be the uppermost side with the sound plat is facing down. The glue should extend down into the gap about ¼ in. all the way across. I used the polyurethane construction glue because it is easier to cut through than the marine sealant in case the transducer must be removed.

When this glue is dry, the transducer will be solidly imbedded in the fish. Check the positioning and if it is not ok, the glue can be cut and done again. This is the reason to not go crazy with the glue! Next, position the fish with the sound plate up and apply glue all around the sound plate. The large area where the bevel was cut in the front wall of the slot can be filled with glue. Force the glue in about ¼ in. The glue can be seen from the lexan side by looking into the box .The glue should be just visible coming up the sides past the sound plate. When this glue is dry, trim the excess flush with the sound plate.

The polyurethane glue has a rough appearance when it is trimmed. It usually appears to have numerous tiny bubbles in it. Fill this surface with wood putty or other filler. Sand and file the area smooth. Shape the transition between the wood and the metal sound plate for the best possible continuity. Finally paint the glued area but leave the sound plate bare aluminum. Clean any glue or paint off the sound plate and do not wax or otherwise coat the surface. The water must “wet” the surface to prevent cavitation.

At this point, the buoyancy should be tested. The object is to determine how much weight should be installed to make it sink. Place the entire fish in a basin of water and



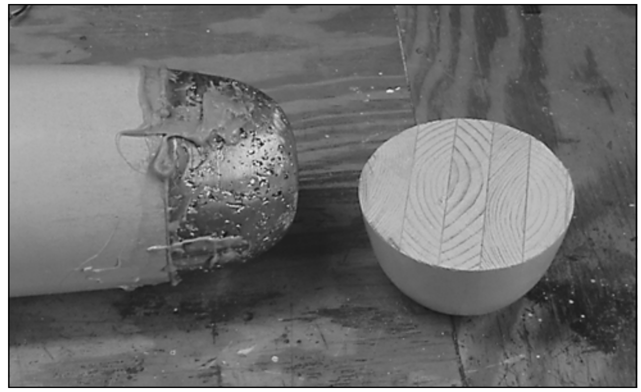
Buoyancy testing in the bathtub

determine how much weight will cause it to sink. I used a scuba soft weight and my bathtub. The fish required about 5 lbs to just sink. This is the necessary weight to achieve neutral buoyancy. Another 5 or 6 lbs must be added to make it sink while being towed. Note the total amount of lead required.

To provide the necessary weight, and maintain the hydrodynamic shape, a cast lead nose is installed on the fish. First a cement mold is made of the existing nose and then the correct amount of lead is melted into the mold. The shape of the lead will exactly duplicate the existing nose. The wood nose is then cut off and the lead nose is glued and screwed in place.

Position the fish in a bucket of cement and allow it to set. The fish nose should be greased

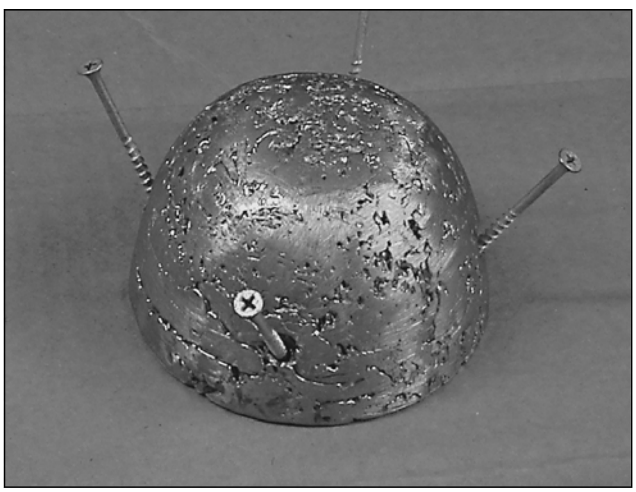
Making a cement mold of the nose shape



The original wood nose is cut off

to prevent the cement from sticking to the fish and allow mold release. I used regular axel grease. The cement is fast setting mortar mix.

Weigh the lead and set aside the correct amount. Old scuba weights are convenient since they already have known weights. Melt lead into the mold and try to remove most of the slag and dirt from the surface of the melted lead. You want a flat clean surface to glue to

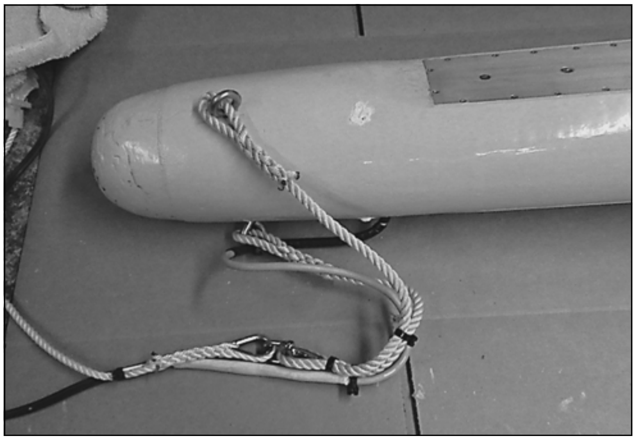


The cast lead nose

the fish. After casting, drill four holes for the long screws that will hold the nose in place. The screws should be counter bored in the lead, so they will be flush when they are installed. I used galvanized deck screws and drilled them at an angle.

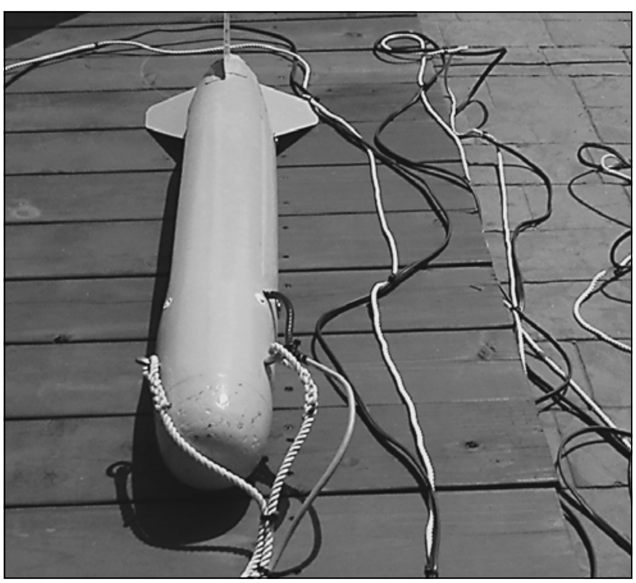
Measure the lead casting and cut off the wood nose of the fish to the same dimensions. Be careful to make a square cut. File the flat side of the lead to remove slag and dirt and expose clean metal. With the fish held in the vertical position, the lead can be easily glued in place. I used the polyurethane construction glue because the paint applies better over it than the marine sealant. Squeeze out the glue and gradually tighten the screws to center the lead in position. Fill the screw holes and coat the screws with glue to prevent water from getting into the void. The rough surface of the lead should be smoothed and filled with glue and wood putty. The glue will fill large gaps and the putty will allow sanding to a smooth finish. When the glue and filling is dry, the joint between the lead and wood can be filed to a smooth transition. After painting, the seam will almost disappear.

The bridal is attached to two eye screws which are inserted ahead of the slot and behind the lead nose. The geometry of the bridal is an area for experimentation. You want the fish to go through the water in a horizontal attitude. I tried several positions for the bridal attach



The bridal attachment is an area of experimentation

points. A little behind the lead and partially down the sides seems to work. One eye screw is ahead of the place where the cable emerges from the fish. This makes it easy to tie-wrap the cable to that leg of the bridal. Drill the pilot holes for the eye screws with a bit size that insures a tight fit, but not so tight that there is danger of splitting the wood. Practice with scrap wood to determine the optimum size pilot hole. Stagger the angle of the two eye

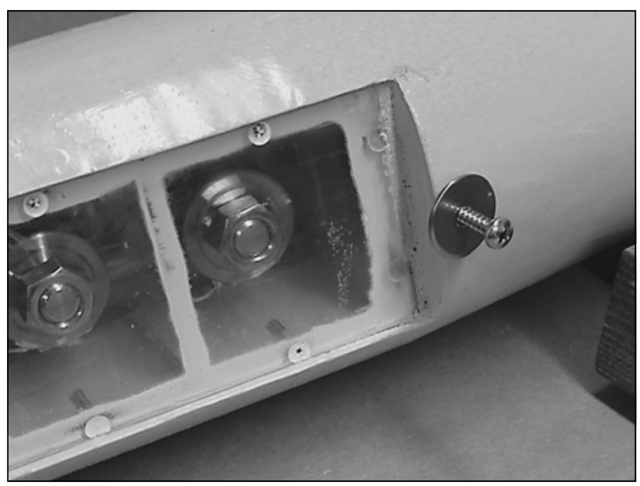


The fins can be bent to fine tune the towing attitude

screws slightly so they will not meet in the center of the fish! The eye screws should not be positioned too far down the side of the fish or the water flow across the sound plate will be disturbed.

The towing attitude, in the water, is dependant on many factors. Shape, weight distribution, fin adjustment, tow cable resistance, and bridal geometry all have an influence. You will have to adjust these factors until the fish tows the way you want it to.

The bridal is fabricated from 1/4” nylon line and attached to the eye bolts with woven splices. The tow line is attached to the thimble and tie wraps are adjusted to give the correct relative length to the two arms of the bridal. This is an area for experimentation to determine the best angle for the sound plate. The look-down angle can be varied to suit the requirements of your search. With this bridal it is easy to adjust. Use the high quality tie-

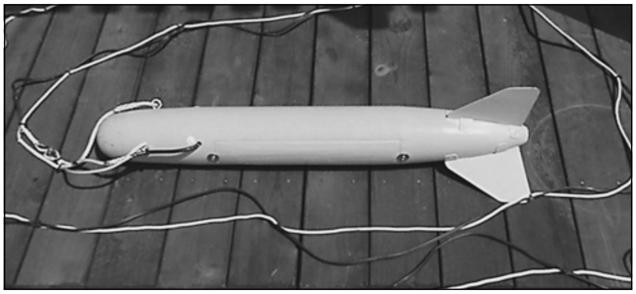


The transducer interior is easily inspected

wraps with metal gripping inserts. They are easy to adjust to a precise tension.

The wood cowling is shaped to cover the lexan side of the transducer and maintain the

hydrodynamic shape. Cut a piece of wood, of the type used in constructing the fish, to fit in the slot above the lexan. The fit should be loose, since the wood may swell or warp



The wood cowling protects the back of the lexan box

somewhat with use. With the lexan side facing up, and the wood piece in place, use a wood plane to shape the piece to match the contour of the surrounding fish. The water will freely enter around this piece but it will maintain the hydrodynamic shape of the fish and protect the lexan surface. The cowling is secured in position by two screws and wide area washers with one screw at each end of the wood piece. The screws are long enough so they don't have to be completely removed to lift the wood piece out. Simply unscrew one of the screws about 1 in. to allow the wood to lift out. The wood cowling can be left in position during a period of usage, but it should be removed to allow the interior of the slot to dry out after use.

The cable from the transducer is joined to the tow cable wire by a waterproof splicing technique. This is quite critical because of the high voltage transmit pulse and the water pressure at depth. Any water intrusion will soon result in a total short. The illustrations on the following page show one method of making a waterproof splice, suitable for high voltage. I don't recommend trying to use a connector here, even though it would be convenient!

Testing the Drivers and Transducer

The drivers should be tested before they are installed in the transducer array. If any parameters are too far from normal, the driver should be rejected. Since the drivers are connected in parallel, and all driven from the same source, they will only have equal output if their characteristics are the same.

When the transducer is finished, using the tested and accepted drivers, it should be tested as an assembly. Don't wait until the fish is finished, with the transducer glued in, to find out that it doesn't work!

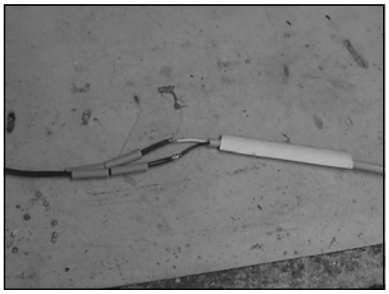
The testing process is interesting and fun. It gets into a seldom explored area of electronics: interaction with resonant mechanical devices. The following section describes the different parameters that can be tested.

DC Resistance

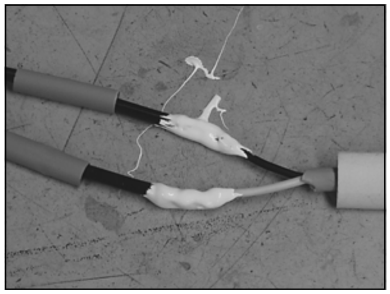
The piezoelectric material is a non conductor and responds to the electrical field and not current flow. A good driver is an open circuit when tested with a conventional ohm meter. Any DC resistance is caused by moisture intrusion into the piezoelectric material. Water can enter the void inside the driver, past the bolt threads at the top or bottom, and once inside, will never dry out. Of course, this destroys the usefulness of the driver because the high voltage transmit signal will arc across this wet area.

The most likely path for water intrusion is through the bottom mounting hole. The flat head screws pass through the sound plate and

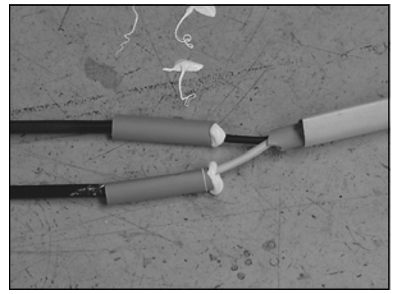
Cable Splicing



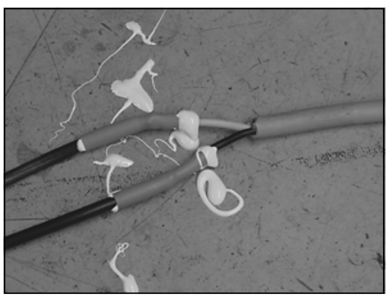
1. Install heat-shrink over the wires and solder the connections



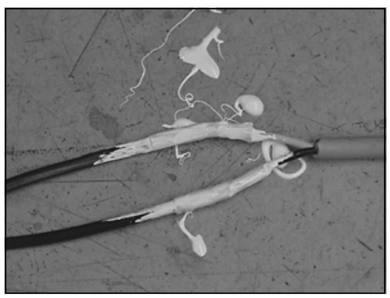
2. Coat the connections with sealant



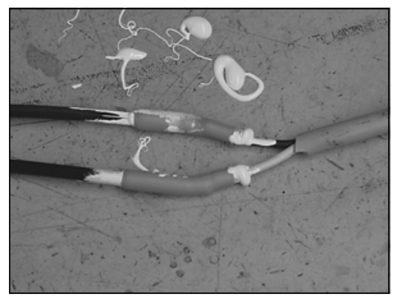
3. Move the heat-shrink over the sealant



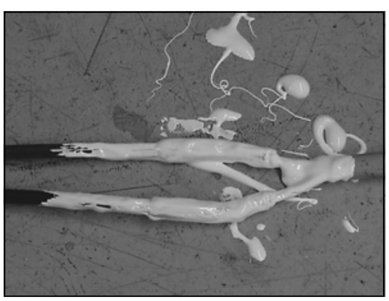
4. Shrink the first pieces of heat-shrink until sealant squeezes out



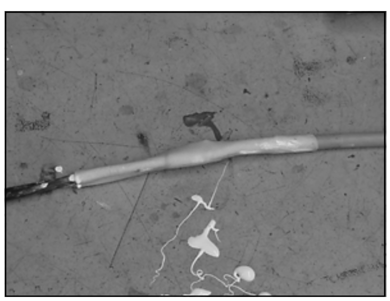
5. Coat the heat-shrink with sealant



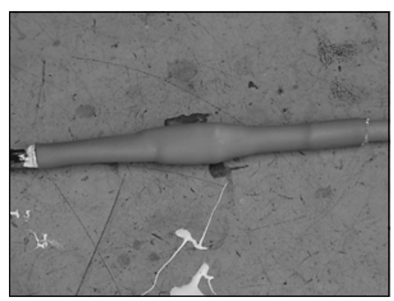
6. Slide the second pieces of heat-shrink over the connection and shrink



7. Coat the overall connection area with sealant



8. Slide a larger piece of heat-shrink over the connection and shrink it



9. Slide the last piece of heat-shrink over the connection area and shrink it

into the tapped slugs threaded into the drivers. Since the driver is not sealed internally, the screw and the slug must be completely sealed when assembling the transducer. This will stop water from leaking past the flat head screw threads, the driver bolt threads, and into the interior of the driver

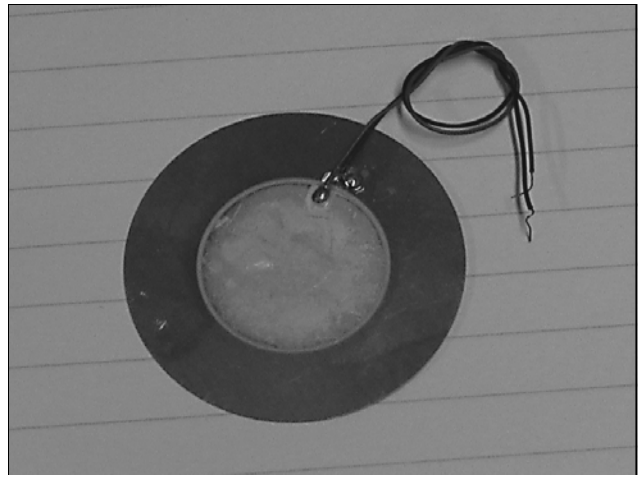
Moisture must be kept out of the transducer lexan enclosure for the same reason. Desiccant material is enclosed inside the transducer to prevent condensation. If rust appears on the driver top nut, it is a sure sign that water has intruded.

The DC resistance of the transducer should be checked often. The best instrument to use is an old fashioned analog VOM on the highest ohms range. These meters have sufficient open circuit voltage to detect leakage up to several megohms. If leakage is detected, the problem might also be in the tow cable or the water-proof splice. This is much easier to fix than the transducer itself.

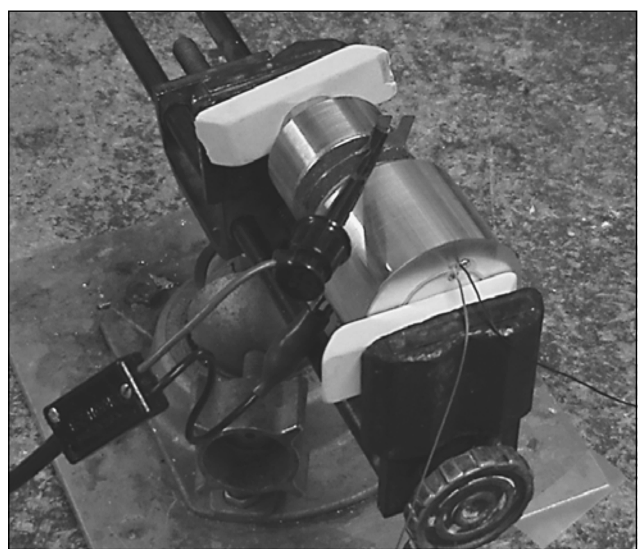
Polarity

All the drivers must be the same polarity. The piezoelectric material expands and contracts in response to the polarity of the applied voltage. This physical change of size stretches and relaxes the bolt and this oscillation pushes and pulls against the sound plate. We want all the drivers to push and pull together in the transducer. If one driver happens to be contrary, it will partially cancel the other drivers and the beam will be weak and distorted. To avoid this problem, test the polarity of each driver before assembling the transducer.

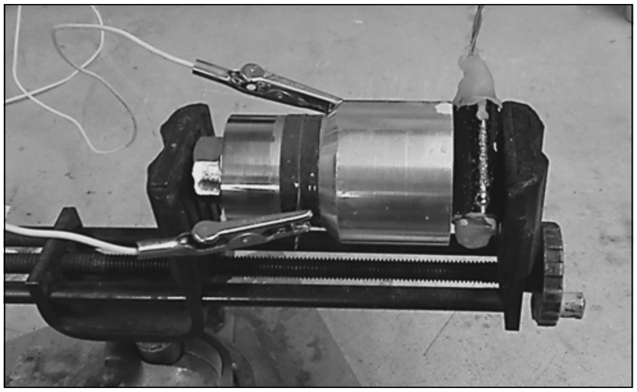
The polarity of a driver can be checked by clamping it to a piezoelectric disc or hydrophone element and comparing the output phase with the input phase. Stimulate the driver at its resonant frequency using an audio oscillator and view this signal on channel A of an oscilloscope. View the piezoelectric disc or hydro-phone output signal on channel B and note the phase relationship between the two signals. Next, substitute the other drivers into the setup, one at a time, and verify that they are all similar. Although the signals displayed on the scope will not be exactly matched in



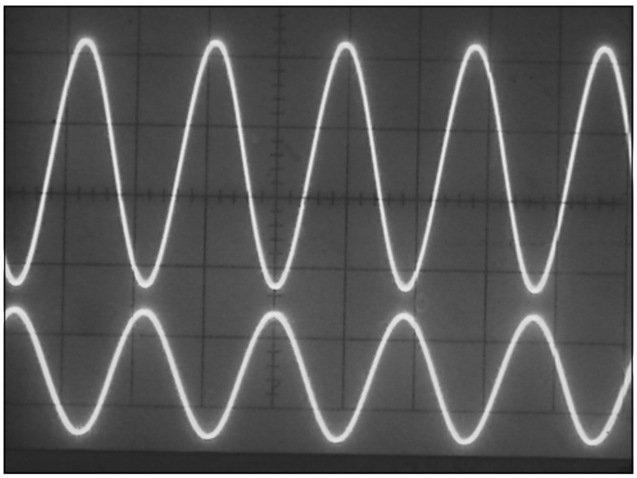
Piezoelectric buzzer element



Clamp the driver and piezoelectric element between two rubber erasers



A hydro-phone element will work also



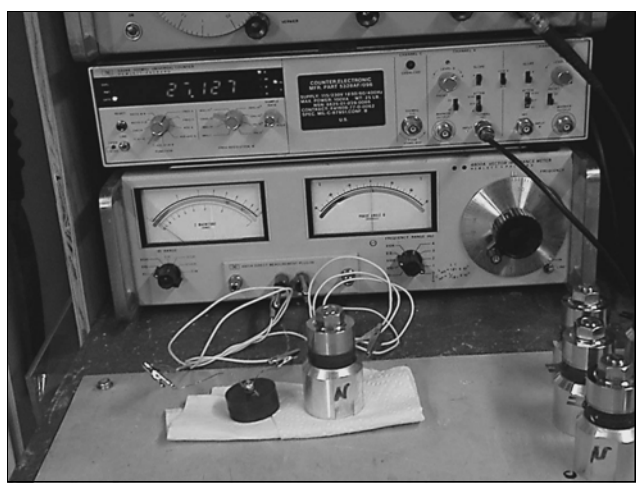
A phase comparison as viewed on the dual trace scope

phase, it will be obvious if one driver is reversed in polarity. The clamping tension must be adjusted to get a good output which is viewable on the scope.

Unfortunately, if you find a driver with reversed phase, you cannot simply reverse the wires because one side is grounded to the sound plate in all the drivers. If you obtain all the drivers from the same source, it is not likely that one will be reversed. It is important to check, because it will be nearly impossible to detect this problem after the transducer is built. It simply will not work properly.

Resonant Frequency

The drivers used in a transducer must be similar in resonant frequency. When the driver is energized without a load the resonance is very sharp. This makes it easy to verify the frequency. Connect an audio oscillator and a frequency counter to the driver, and using a current probe, tune the oscillator until a dramatic increase in current is noted. This is the resonant frequency. A dip will also be noted in the amplitude of the audio signal which is caused by the driver impedance dropping at the resonant point. Use a dual trace scope to view the current probe output and the input signal at the same time. Trigger the scope on the input signal. With this setup, you will observe the current increase and peak at about the same frequency as the signal dips. The phase relationship between current and voltage in the system can also be readily seen. With no external inductance added to the system, the current and voltage will be nearly 90 degrees out of phase.



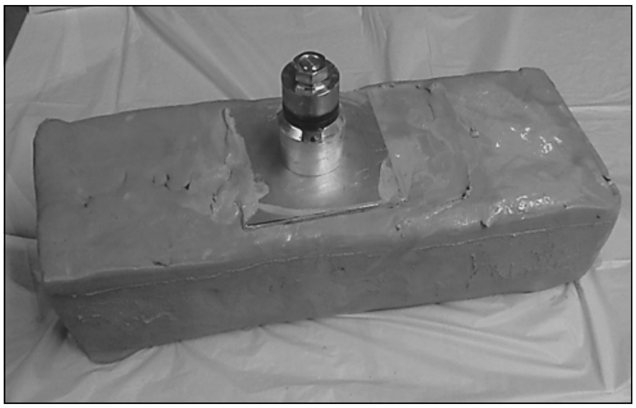
Checking the resonant frequency

For this test, all we want to do is make sure all six drivers have similar resonant frequen-

cies. They should be within a few hundred Hz. Do not use any driver which seems different in any way. We want all the drivers to be well matched.

Testing With a Load

The ultimate test of the driver is how much force it can deliver to the water, in the form of vibration, and its efficiency at converting electrical power to physical power. To measure



A metal plate imbedded in clay is a suitable load

this directly requires calibrated hydro-phones and other instruments which we don't have. Fortunately an indirect method is accepted as being almost as good and much easier. The indirect method uses the change in electrical impedance, measured with and without physical load on the driver, to indicate the power delivered to the load. It assumes that, an increase in power consumed by the transducer, when a load is attached, is power entering the load in the form of sound. The ratio of the power consumed by the bare driver and the power consumed by the driver with load is the efficiency of the driver.

To test the driver, a load is needed which simulates a large mass of water and will dissipate the vibratory power generated by the driver. It seems like any massive object would work, but this is not the case! I tried blocks of metal, wood, and cement, tubs of water, and finally, a swimming pool. All were useless.

Most materials are good sound conductors and will reflect sound energy back to the driver from the interior of the load material. This reflected energy varies the acoustic load on the driver and results in electrical impedance changes which obscure the change that we are trying to measure. Depending on the frequency, numerous resonant modes are possible in any piece of material big enough to serve as a load. Since these materials transmit sound efficiently, many of these modes will be as pronounced as the actual mechanical resonance of the driver. These interactions within the load material are called standing waves.

A swimming pool, with smooth concrete walls, is a nearly perfect reflector of sound energy under water. This makes it hopeless as a testing situation. A pond with a sloping dirt bottom is better. The best possible load is a body of water which is large enough so that no reflections return to the driver under test. You can do testing, in deep water, from a boat or from the shore of a large body of water. I tested the transducer in a marina from a dock. Strong reflections were observable even with this much water volume.

We want a load where all the power delivered by the driver is dissipated. The Navy has both open water test ranges and anechoic test tanks for their research. An anechoic tank has baffles that endlessly redirect the sound until it dissipates. These are large scale facilities, out of reach to the amateur builder. We have to improvise.

Happily, wet artist's clay works very well as a load for ultrasonic testing. This refers to the real, earth, type of clay and not the plastic type. No sound reflections were observed in a 20 pound lump of clay when the drivers were tested with the audio oscillator. I assume that the clay has poor sound conduction qualities because the tiny particles of clay are not bonded together except by the water contained in the clay. The sound energy is used up and dissipated while rubbing these fine grains of clay against each other. At the same time, the clay is very massive and similar to water in density. In acoustic terms, it is a good impedance match to the driver. Unlike a dry material, it will stick to the driver face and transfer power without being actually bolted in place. It is a little messy, but cheap, and easy to store in a plastic box.

Using the clay load, the characteristics of the driver, under load, can be investigated. When attached to the clay load, the resonance will be less pronounced and the electrical impedance will be greatly increased. Much more power can be applied to the driver before the vibrating masses reach their maximum safe amplitude. The resonant frequency will be lower than without a load.

To test the drivers, attach them one at a time to a metal plate which is imbedded in the wet clay. If a threaded slug is mounted on the plate, the drivers can be screwed on, one at a time, without moving the plate. This will insure consistency in the load. The test equipment is connected as described in the resonance test. A dramatic difference will be noted with the load attached.

When testing the driver, if you tune the audio oscillator through the ultrasonic frequency range, you will find more than one resonant frequency. Some of these resonant points are weak and some are very strong. We want to operate at the lowest resonant frequency. This will be near the specified frequency of the driver unit. The drivers that I used were specified as 28 KHz units but in the sonar they operate at about 24.5 KHz. They have several resonant points at frequencies above 28 KHz but none below.

Testing to Determine the Operating Frequency

The piezoelectric driver is a reactive electrical load. This means that the current and voltage at the driver terminals will not be in phase. If you monitor the phase difference, while tuning the audio oscillator through the resonant frequency band, you will see the phase vary from nearly 90 degrees to nearly in phase, but it always remains on the capacitive side. This is because the piezoelectric disc consists of two metal plates separated by a dielectric material, in other words, a capacitor. In this case, we are interested in the piezoelectric properties of the dielectric and the capacitance is a by-product.

The mechanical output of the driver is closely coupled to the electrical input and vice-versa. This is what it is supposed to do, but it makes the design process a little more difficult. The reactance, measured at the input of the driver, is comprised of the capacitance of the piezoelectric material and the mechanical resonance, coupled back to the input circuit. The mechanical resonance can be either leading or lagging the frequency of the driving AC voltage. The relationship between these two forces causes the phase changes that are

measurable at the input terminals. If the mechanical resonance and the drive frequency are the same, the capacitance alone will cause an overall capacitive reactance.

To apply power to the driver, the amplifier must be designed to match the impedance of the driver. In DC electronics, impedance is simply the ratio of voltage to current. In AC electronics the phase difference between the voltage and current also enters the equation. As mentioned above, the driver electrical impedance changes with the mechanical load and the drive frequency. The design task is, find the best frequency of operation for the driver, measure the impedance at this frequency, then design the matching circuit.

To simplify the problem, the capacitance is nullified by placing an inductor in series with the input to the driver. The inductance is adjusted until it resonates with the capacitance of the piezoelectric material near the mechanical resonance frequency. This can be observed as a change of phase between the voltage and current of the input voltage. With the correct inductance, the voltage and current will be nearly in phase. This is the condition of best efficiency.

The mechanical resonance reflects back to the input and this is also measured as a change of phase in the input voltage and current. If the frequency is varied, the full range of phase change can be observed. With inductance in the circuit, it will be possible to observe both capacitive and inductive reactance. The series inductor and the influence from the mechanical resonance are interactive and cannot be separated!

We want an in phase condition, or in other words, a resistive load, because the amplifier is designed to function with a resistive load. If the voltage and current are in phase, at the input, the load is equivalent to a resistor, even though no actual resistors are present. The power delivered to the driver, which is transferred to the water as sound energy, can be viewed as having been dissipated in a resistor, which is equal to the impedance of the driver. A small portion of the input signal is lost to friction within the driver and this is also added to the resistive equivalent load.

If the inductor value and frequency are both varied around the expected operation frequency, many combinations will result in an in phase condition. The resonant frequency becomes lower as more inductance is added. Too much inductance will force the resonance lower than the optimum and the actual output will fall off. If you observe the current magnitude, there will be a band of frequencies and inductance values that result in maximum current. This is the condition that we want.

The increase in current corresponds to the mechanical resonance, and power being delivered to the load. The mechanical resonance peak means that the driver masses are oscillating at their maximum amplitude and delivering the maximum physical displacement to the sound plate. By monitoring the electrical situation at the input terminals, we can determine the best operating frequency.

My experience testing these drivers indicates that the optimum situation is with the minimum inductance value that will cause the voltage and current to approach an in-phase condition. It doesn't quite reach an in-phase condition unless excessive inductance is added. It is not necessary for the current and voltage to be exactly in phase. When this

nearly in phase condition coincides with the maximum current, it is an efficient operating condition. Record the frequency and value of inductance.

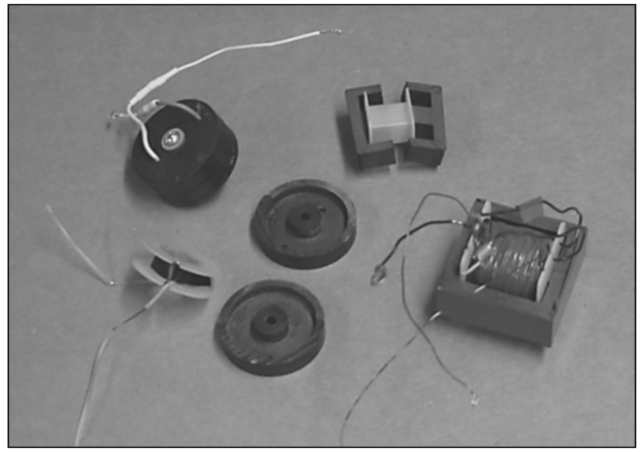
Test all the drivers with this test setup without changing the load condition. The drivers should all yield similar results. Reject any that are inexplicably different.

In the sonar system, we are powering a group of drivers, connected in parallel, and arranged in an array. The above testing information refers to one driver, but the principle is the same when testing an array of identical drivers. You should practice with a single driver until your test setup is developed and the measurements are completely understood.

When the completed array is tested, the measurements are not as clearly seen and the resonant band is a little less well defined. This is because of the differences between the individual drivers and the interaction caused by being mounted on the sound plate. The lexan box is also a parasitic load on the sound plate. This is reflected in the impedance readings. Of course the actual impedance measured will be much lower because you are powering six drivers in parallel. The object of the test is to find the best operating frequency of the array, and the value of inductance required.

The Inductor

Normally inductors are measured with a bridge at a 1000 Hz frequency. The values of inductance referred to in these plans are measured this way. Depending on the type of inductor, the effective inductance may be much different at 24 KHz. Iron core inductors have loss which increases with frequency. Be sure to use a core material that is suitable for the frequency of operation. The ferrite core that I specify will work, but other components may also be ok. The size of the core must be large enough to avoid saturating during the output pulse. To make it easy, I used the same type of core for both the output transformer and the inductor.



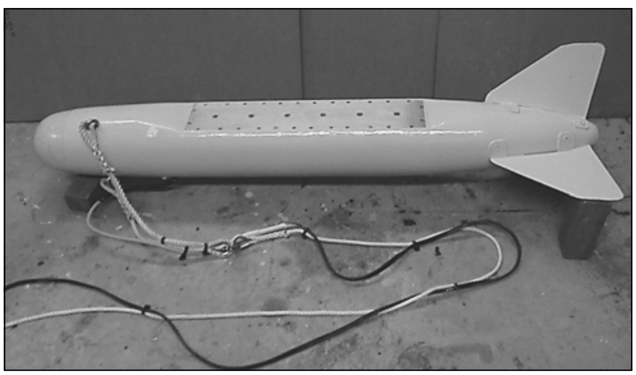
Ferrite core inductors

Bench Testing with Clay vs. Water Testing

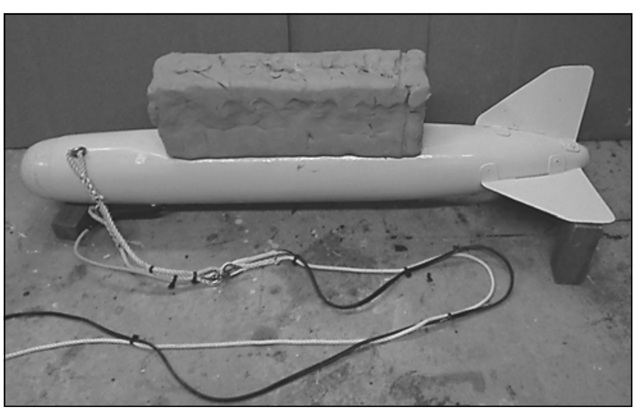
The clay load makes testing the transducer possible, on the bench, where the test equipment is easiest to use, but it is not a perfect substitute for water testing. If you don't have a suitable boat available, the testing can be done at a dock in the harbor, or at a large pond. As mentioned above, the body of water must be large or have non reflective bottom and sides. A swimming pool will not work. The rough testing can be done with the clay load and the fine tuning can be done in the water. As detailed above, the inductor value, the load, and operating frequency are interdependent. Changing from the clay load to the water will alter the impedance and the other parameters somewhat.

I found that the clay load worked well testing the transducer, but the frequency-of-operation test result was different by about 500 Hz. This indicates that the clay is not a perfect substitute for the mass of the water. This is no surprise.

The clay must be pliable but not dripping wet. Shape it to cover the sound plate with as much mass as possible above the plate. I used a 20 pound lump. It works best to set the transducer on a surface with the sound plate up. It is difficult to get the clay to bond evenly on the sound plate without air pockets trapped under the clay. If there is uneven bonding, you will observe distinct minor points of resonance along with the principal resonance. This is the result of uneven load on the different drivers!



Set the fish in a level position with the sound plate upwards



Shape the 20 Lbs of wet clay to fully cover the sound plate

Record the frequency when you finish testing. This will be the sonar transmitter frequency. Measure the voltage and current readings using the scope and current probe. Remember to convert from peak-to-peak readings on the scope to RMS volts. Record these to determine the impedance. To verify the calculated impedance, substitute a resistor of the same value into the test setup. It should yield the same voltage and current readings as the transducer with load. The power amplifier must be designed to power this impedance with the desired power.

Power Output

My transducer measured about 60 ohms at 24.5 KHz with a 0.9 mH inductor. To deliver 300 watts to this load, 134 VAC is required at the output of the amplifier. This is realized by adjusting the turns-ratio of the output transformer. The drivers are specified at about 50 watts each. With six units in the transducer, 300 watts is a safe power level to apply.

There are many subtleties about the power rating of drivers and especially multiple drivers connected together. I haven't found very much reference information about the maximum power that can be applied. I assume that if you over power the drivers, they will be damaged. The pulse width matters too. It takes time for the oscillation of the drivers to build up. If the pulse is short, the oscillation cannot build up to destructive amplitudes. The pulse width that I use is just long enough for the oscillation to reach its full amplitude. I will leave it for others to find out how much power can be applied to these drivers.

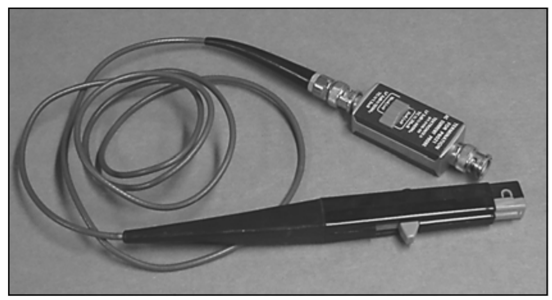
Testing the System

The world of ultrasonics is not well covered by conventional test equipment. I am referring to new or surplus, quality, equipment such as HP, Tektronix, and also hobbyist and ham radio type test equipment. For example, I haven't found a good, lab quality, 24 KHz pulsed signal generator among the usual equipment available. Many RF signal generators can be pulse modulated, but they seldom extend below 50 KHz in frequency coverage. Many function generators can be pulse modulated, at 24 KHz, but they have poor frequency stability and rudimentary output calibration. To do meaningful measurements on your system, you need quality equipment. Once again, the amateur builder must be willing to improvise.

The equipment mentioned in this book, and seen in the illustrations, is my solution to the problem. By connecting together different pieces of equipment, you can do all the necessary testing. I have pictured some of the test equipment items that I use. These are not the best, or only, units available, but they illustrate what functions are needed to check out the system. If you want to go first class with test equipment, it simply means obtaining newer examples of the same basic functions.

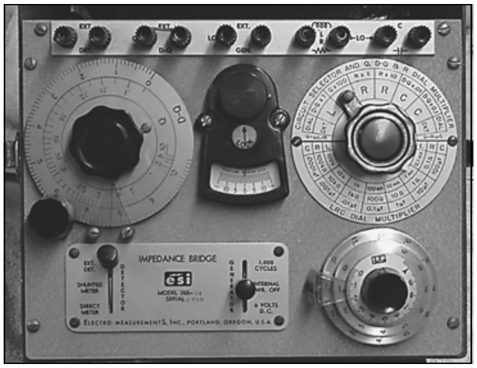
When you collect your test setup, be sure to obtain real, lab quality, test equipment whenever possible. Better to use a 30 year old audio generator from HP, than a new, cheap, hobbyist generator. The difference is quality and stability. Measurements on the sonar are often tricky and not always consistent, and if you add the uncertainty of flakey, cheap, test equipment, it becomes really annoying.

Electronic filter: (Khrone-Hite 3103) This is a variable high pass and low pass filter which can be adjusted to form a band pass filter of any bandwidth. Use it to condition the signal from a hydrophone and eliminate interference from unwanted signals.



Current Probe: (Tektronix P6021) This is a clamp-on transformer with a calibrated output voltage proportional to input current. Normally used with an oscilloscope to view current waveforms. Use it to display the phase of the current feeding the transducer. To measure phase, display the voltage waveform on one trace and the current waveform on the other trace. To measure impedance of the transducer, note the current value, voltage value, and phase. Calculate according to Ohm's law.

Depth Finder Test Set: (EDI DSTS-3B) This instrument measures the power output of a depth finder or sonar, generates a calibrated time delay, and outputs a simulated reply echo signal. This is the closest to a complete sonar test set that I found. It is very useful for operational tests on the sonar.

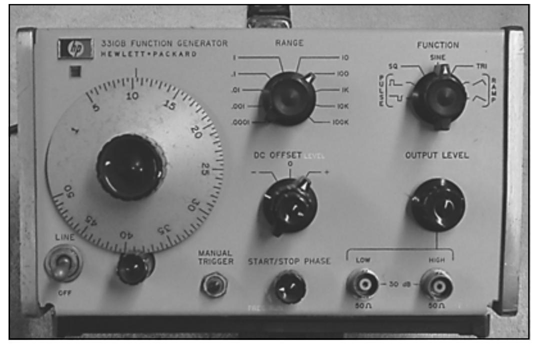


Impedance Bridge: (ESI 250) This instrument is used to measure inductance and capacitance. It will also indicate the quality of the component by measuring the losses in proportion to the value of inductance or capacitance.

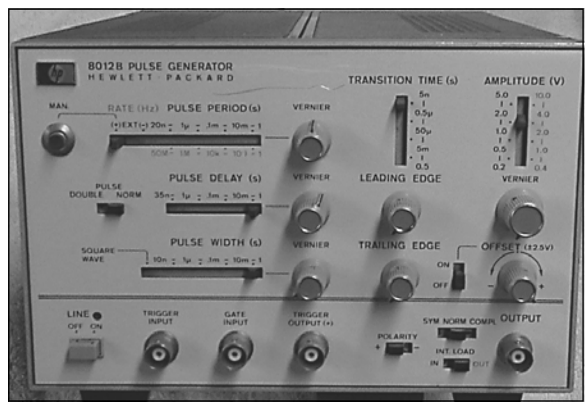
1) Audio Oscillator: (HP 651B) This instrument is fundamental for sonar. Use it to test the receiver. This model has high stability and a calibrated output attenuator.

2) Frequency Counter /Timer: (HP 5328A) This unit is used to measure time delays, period, and frequency.

3) Vector Impedance Meter: (HP 4800A) This instrument directly measures the impedance and phase angle of a component. It can be used to evaluate a driver or complete transducer at its operational frequency. It is also very useful to measure the characteristics of high frequency transformers.



Function Generator: (HP 3310B) This is a general purpose signal source that covers a wide range of frequencies. It will not substitute for the audio oscillator. In general, only very expensive function generators have adequate calibration and stability for sonar work.



Pulse Generator: (HP 8012B) This instrument is necessary to simulate the different time delays and pulse waveforms encountered in the sonar system. Use it to simulate trigger pulses, receiver output pulses, and to modulate a function generator to obtain pulsed signals.

General Testing Guidelines

I can't provide a detailed step-by-step procedure for checking out the entire system. Your level of understanding of the circuitry, and the test equipment available, will determine the methods and extent of testing. If your primary interest is electronics, you may really get into the testing and improvement of every aspect of the system. You may try to wring out the ultimate performance possible. If your primary interest is diving, you may get on with using the system and forget about the finer details. Even when it is not optimized, the sonar is better than nothing! Since this is a true homebuilt system, some testing, tuning, and adjustment is to be expected. I hope your primary interest is actually having fun. It defiantly has been fun for me to design and build it.

The circuit boards should be checked out as much as possible as they are assembled. The different functions can be de-bugged, individually, before you try to assemble the entire unit. By using simulated inputs to the different circuits, you can dial them in, one at a time.

The display unit will function, on its own, and can be completely checked out before the transmitter-receiver unit is built. You need a pulse generator to simulate the input pulses, from the receiver, that will print on the paper.

Alternately the receiver-transmitter unit can be built first and checked out. The output section of the amplifier should be designed to power the load presented by the transducer with its inductor. When the load impedance is known, a resistor dummy load can be fabricated to test the system on the bench. Use non-inductive resistors, not wire wound types.

You should provide a means of bypassing the inductor, which compensates for the capacitance of the transducer, when connecting a resistor load to the sonar. Otherwise, without the transducer, you will be presenting an inductive load to the amplifier and your tests will not be valid. I added an additional banana jack which connects directly to the amplifier output. This makes available a direct connection to the system.

You can measure the power output, across the resistor load, with a scope. A 100:1 probe is recommended, for this test, because the voltage output may be close to the safe input voltage of some 10:1 probes. Be careful when you apply the sonar output directly to your test equipment or you will be sorry! I blew my audio signal generator this way.

Use a pulse generator to simulate the trigger pulses from the display unit. Trigger the scope with this trigger pulse and view the transmit burst across the resistor load. With this setup, you can check out the transmit section. The transmit burst should be clean, with minimal droop. You can verify the pulse width and the power.

View the receiver output while the transmitter is being triggered as described above. A strong output will be evident during the transmit pulse but it should return to the normal receiver noise level within a few milliseconds. If noise exists which seems to diminish over many milliseconds, it may be power supply noise leaking into the receiver. The power supply works hard while recharging the output capacitors after each transmit burst.

With the transmitter on standby, apply the

audio signal generator to the input through an attenuator. Check the receiver sensitivity by applying a signal just above the noise level. Verify the gain control functions by observing the variable gain vs. time after the trigger pulse. With a CW signal input you can see the gain vs. time function.

Generate a delayed, pulsed, signal at the operating frequency and apply it to the input through an attenuator. This allows you to observe the pulse response of the receiver, log detector circuit, and output to the display.

When the individual components are working, join the display and transmitter-receiver units together. Adjust the receiver DC level so the receiver noise level, at full gain, will be just below the threshold of printing on the paper. A weak signal input will now cause an indication on the display. When the transducer is in water, the ambient noise will be well above the receiver noise level. The gain control will be adjusted to the level where the signals will be well defined.

Caution: High Power Sound

The sonar is a high power generator of ultrasonic sound in the water. Do not activate it when divers are near. When the transducer is in air, the efficiency of sound transmission is very poor and the resonant frequency is not optimized. I assume very little sound power is transmitted to the air, but I don’t want to take any chances. Do not subject yourself to the sound from the transducer, even though you can’t hear it! Wear ear protection when activating the unit with the transducer attached.

Using the System

The Paper Recordings

When the transmitter operates, generating its pulse of sound power, the receiver is overloaded for a period of time and prints a dark band along the top of the paper. This dark band is wider than the actual transmit pulse because the piezoelectric drivers continue to ring after the powerful transmit pulse. This dark band can be considered the zero range reference on the paper.

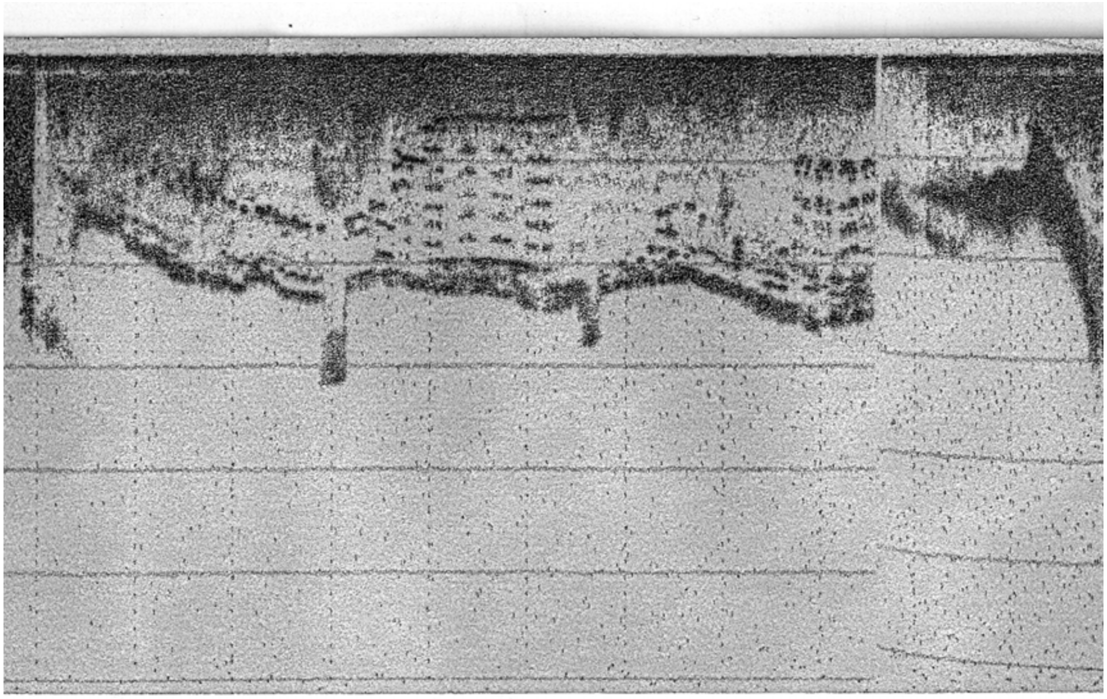
If you visualize the fish being positioned at the top right corner of the display unit window, and the stylus movement from top to bottom being the sound beam, you will have the correct orientation when interrupting the recordings. The paper moves into view, in the display window, from the right side and its movement represents progress of the fish. The fish transmits to the right and the area of the paper represents the area covered by the beam from the fish. The paper recording, moving to the left, shows area that has already been covered. The stylus is writing, in real time, the returns from objects exactly 90 degrees from the track of the fish.

If you are used to viewing the usual fishfinder display, it takes some time to reorient yourself to the sonar display. Basically you are changing from a vertical to a horizontal representation. When you are on the boat and looking at both instruments at the same time, it is a real mind bender!

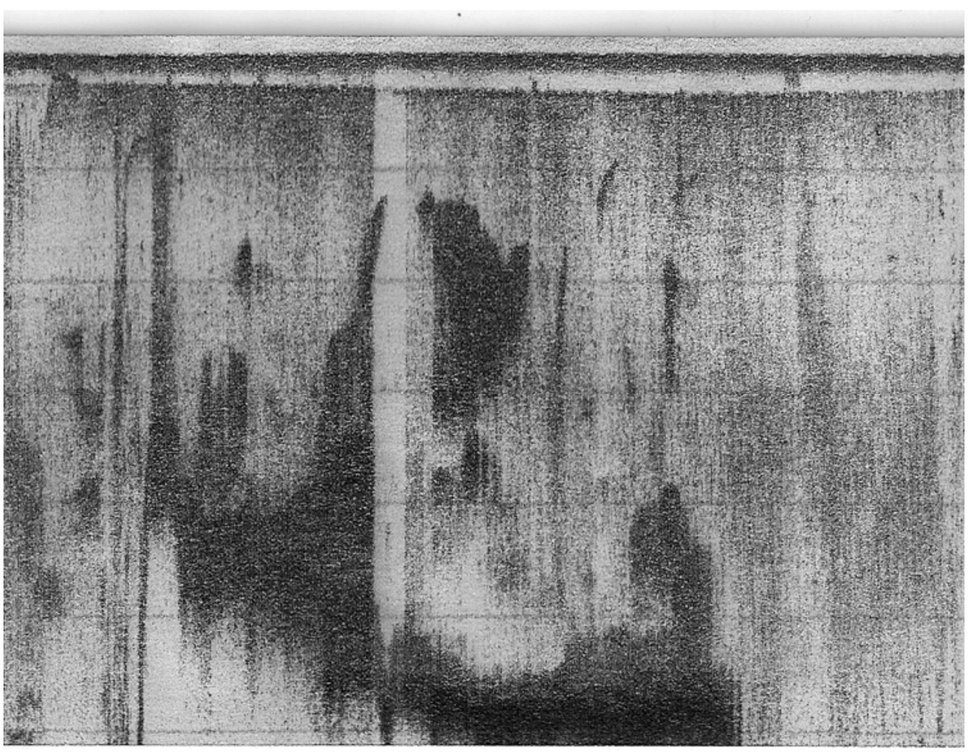
When no return is present, the record will be white. This is sometimes seen as white area behind an object because the sound is blocked by the object. This is also the case in the area before the sound energy reaches the bottom. The gain and STC controls must be adjusted correctly to get the best contrast between objects and sand bottom. Too little gain will result in white areas because of insufficient signal pickup.

The paper recordings reproduced in this book show the typical capability of the system. The most useful range seems to be 600 feet and most of the recordings shown here are using that range. You can count the range lines, at 100 feet each, to verify what range was in use. The distance marks cannot be interpreted unless the boat speed was noted at the time of recording.

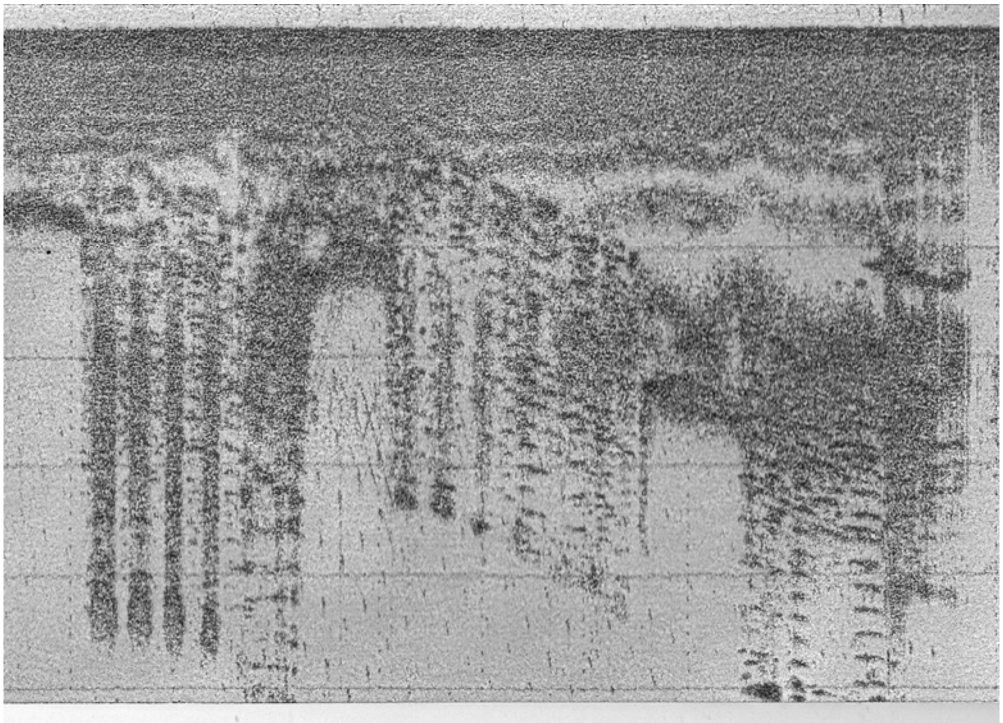
The recording is seldom “square” meaning that the vertical and horizontal have the same scale factor. It is usually compressed in the horizontal dimension. In practice this is not really a problem. To make a recording with an equal vertical and horizontal scale factor, the paper speed and range setup must be adjusted as necessary. It will be valid for only one boat speed. This is not necessary for general searching but is the only way to get a true layout of an area under water.



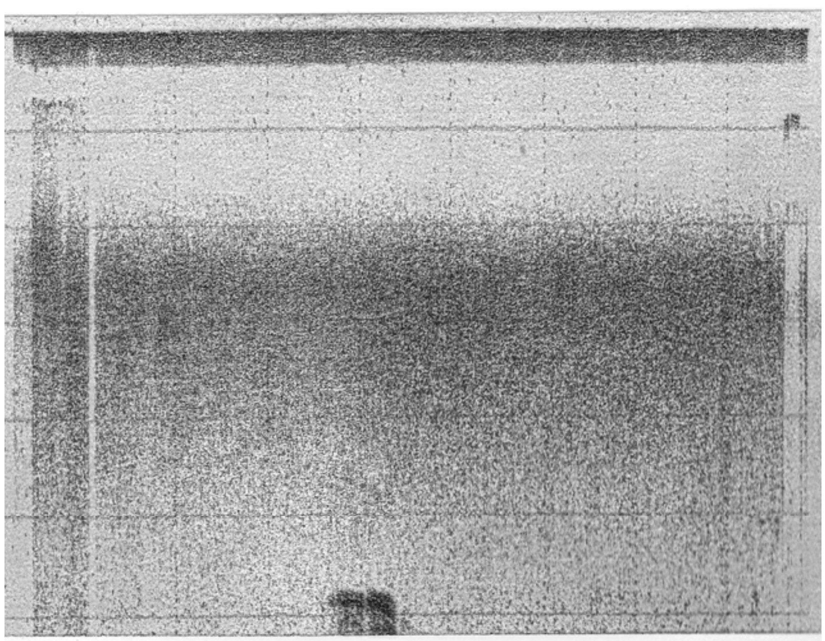
This paper trace depicts the inside of a marina. The water depth is less than 20 feet. From right to left, you can see a rock wall at about 100 foot range, then some boat docks in front of a rock wall. The rock wall stops the sonar beam and nothing is seen beyond about 250 feet. Individual boat docks can be seen along with some large vessels. The large interruption in the rock wall is a boat launch ramp that extends past the wall. The apparent curvature of the rock wall is due to turning the boat. Actually the rock wall is nearly straight.



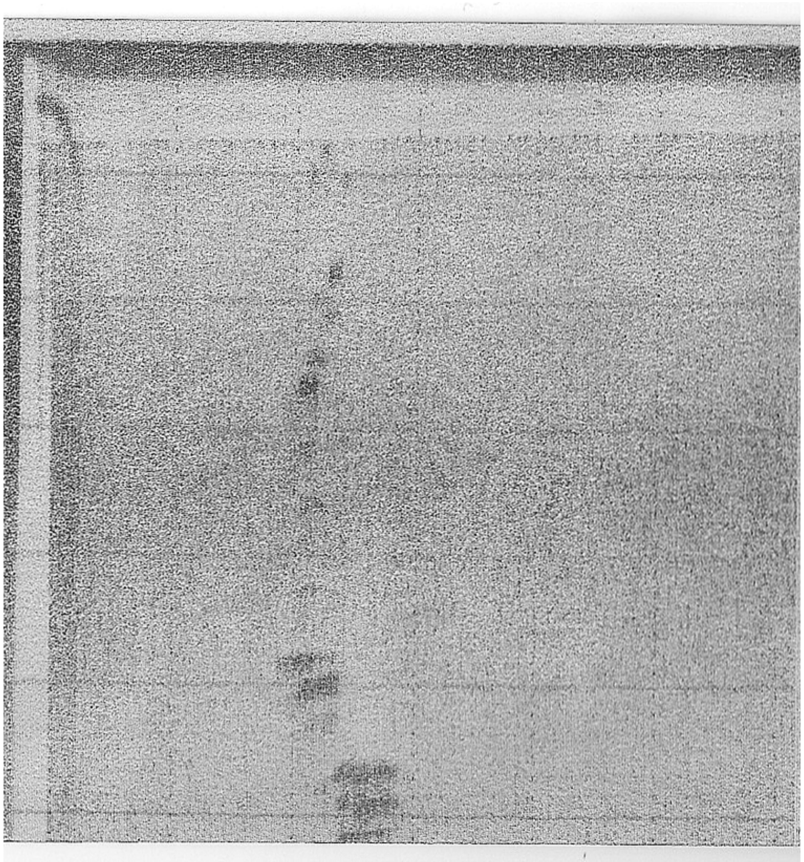
This paper trace depicts large schools of bait fish in water about 50 feet deep. The Sea lions and birds were feasting on the surface at the time this recording was made! The range marks and distance marks are visible.



This paper trace depicts inside a marina in water about 20 feet deep. The boat is traveling down the main channel and passing by many channels that extend to the right. Most of these channels have boats and docks at intervals along their sides. Individual docks and boats can be seen up to 600 feet away. The shading and wave pattern in the short range is caused by the reverberation of the sound in the very shallow water. The apparent curvature of the picture is caused by slight turning of the boat.



This paper trace depicts what we all want to see; a well defined wreck at 600 foot range. The water depth is 100 feet and the bottom is flat sand. There is almost nothing to be seen except the wreck. The fish is being towed at about 30 feet deep and nothing is seen until the beam reaches the bottom at the 200 foot range. The STC circuit has been optimized to keep the printing density nearly constant from 200 to 600 feet. This wreck is a 50 foot barge.



This paper trace depicts multiple objects on the bottom. The water is 100 feet deep and the bottom is flat sand. The objects are actually portions of a ship known as the La Janelle. The relative spacing and orientation can be seen. The display was not perfectly adjusted and the density is a little too dark but the objects were still clearly visible.

Adjustment and Operation

To conduct a search, the sonar system is installed on a boat and the fish is towed through the water. It sounds simple, but the system must be adjusted for the best display of the signals returning from the bottom. This is done, not by scientific means, but by looking at the paper and turning the knobs. It takes practice to get it right. You are actually tailoring the gain vs. time curve to the conditions that exist. The recording paper has reasonable grey-scale range, but the input level to the display circuits is critical. The input to the display must maintain a constant level from minimum to maximum range.

Since the sound signal spreads out as it travels through the water, the signal arriving at distant objects is less concentrated than the signal arriving at closer objects. Therefore the reflected energy is less from the distant objects. In addition, the sound energy is attenuated as it travels through the water. The positioning of the fish above the bottom and the lookdown angle affect the amount of return from the bottom at different ranges. These three factors must be compensated for so the paper will have uniform density of printing from short to long range. The variation of gain necessary to compensate for the signal attenuation is controlled by the sensitivity / time control system.

The STC system is adjusted to automatically increase the gain at a precise rate as the stylus moves across the paper. This compensates for the weaker returns from greater ranges. Ideally we want uniform density of printing across the paper, but the variation of gain necessary is not a simple linear function. With careful adjustment of the circuit provided, a reasonable display can usually be achieved. The challenge is doing this delicate adjustment while maintaining your boat speed and course and watching the GPS!

The STC works by reducing the receiver gain when the transmitter is triggered and increasing the gain as the stylus moves across the paper. This gain variation is repeated for each stylus sweep across the paper. The amount of gain reduction is controlled by the compression control. The rate of return to higher gain is controlled by the slope control. The overall amplification is controlled by the gain control.

Typically, without STC action, the short range part of the paper will be too dark and the long range will show no returns. If the gain is increased enough to show some return on the long range end of the stylus sweep, the short range end will be saturated. By advancing the compression control, the saturated short range area of the paper can be reduced to the correct density. The slope control can then be adjusted for the best compromise of density across the paper. By juggling the three controls, the optimum STC action for the conditions can be achieved.

In very shallow water, the transmit signal will reverberate from the surface to the bottom multiple times. This shows as a dark area in the first 100 feet of range. If short range operation in shallow water is required, the STC circuit can be adjusted to do its entire compensation action in only the first portion of the sweep. With careful adjustment, display of objects at less than 50 foot range is possible.

In deep water, the opposite case exists. There will be an area of no return at the beginning of the sweep until the first edge of the beam strikes the bottom. Depending on the height of the fish above the bottom and the look-down angle, this can be as much as 200 feet. You can disregard this area and adjust the STC controls for the rest of the display.

If the bottom is sand and has few features, the gain and STC should be adjusted for light shading across the paper. If the return from the sand is enough to lightly shade the paper, any object on the sand will show up strongly. If the bottom has rocks and reefs, adjust for the best contrast and the best grayscale picture of the bottom features. You will have to not only practice adjusting the system but also interpreting the display. It really helps to practice on known objects. An isolated wreck on a flat sand bottom is the easiest to start with.

Set the GPS active waypoint to the wreck location. Now you can pass by the wreck at any known distance using the GPS as a guide. You can compare the sonar display with the known size and shape of the wreck. One way to do this testing is to set up waypoints in a grid pattern around the wreck. Then move the boat from one waypoint to the next being careful to stay on the exact track between the waypoints. The sonar should accurately report the distance from your test track to the wreck.

While testing, you will notice that the beam is quite sharp in azimuth. To test the beam, display the return from a long rock breakwater at about 300 foot range. If you travel parallel to the rock wall you will see a steady distance of 300 feet, but if you change direction, you will see that the apparent distance changes dramatically as the fish is turned. The beam is striking only the point on the rock wall that is exactly 90 degrees from the fish and that point will sweep all along the wall to the maximum range. Even though the fish is still about 300 feet from the wall, it is looking at a point far away and the nearest part of the wall is not seen. A rock wall is a very handy sound reflector for testing the system.

The sharp beam is what we want, but yaw in the fish can blur or hide something that you want to see! At long range, a slight yaw of the fish can sweep the beam across a wide area. To view this phenomenon, approach a long straight rock wall at a 45 degree angle and try to maintain a steady course. When the wall comes into range, the printed picture on the paper should be a linear sloping line from long to shorter range. You will see the exaggerated effect of yaw in the wavy line that is actually printed.

For best results, adjust the boat speed so that the fish will not be yawing due to too much corrective steering. Boats steer from the back and if the speed is too slow the corrective steering will pull the tow rope side to side. A longer tow line to the fish will help also. My sonar fish seems to be happy at about 3 to 4 knots.

Searching

Most builders of the sonar will be planning to search for something. Reefs, shipwrecks, fish concentrations, or bottom features can be found with the sonar. A few geometrical problems make the search process more difficult than it seems. The fish is towed behind the boat by a distance determined by the tow line and the depth of the fish. The objects

seen on the display are located at a measured distance from the position of the fish, not the boat position. By the time your brain recognizes the pattern on the paper as something of interest, you have traveled additional distance. If you decide to mark the boat position at this point, how do you accurately get back to the spot that you are interested in? It may be only a few hundred feet, but that doesn't help much in the practical world of diving.

For most diving, you need to drop in very near the spot that you want to visit. It's not practical in technical, or wreck diving, to swim even short distances. You want your shot line or anchor right on the spot. Searching with the boat depth finder is slow and frustrating even when you know you are within a few hundred feet of the spot. The depth finder only looks straight down and covers a tiny area. The methods described here will greatly speed up the process.

A basic method uses a number of marker buoys. These can be as simple as plastic jugs and a brick as a weight. Set the rope length to the depth of the area that you are searching. These should be made up so you can throw them in and the weight will go straight down without tangling.

The buoys are used as visual references. When you note an interesting object on the display, toss a buoy in at that time. On your note pad, draw a plot of the situation. Show the boat heading, speed, and the estimated offset of the object from the marker buoy. Next maneuver the boat to pass by the object on a course 90 degrees from the original course with the same speed. Try to pass by the object at about the same range as the original sighting. Toss another buoy in when you see the object again.

With your situation plot, you can estimate the relative bearing from the two buoys to the spot. Position the boat near the supposed position of the spot and drop another buoy. At this point, pick up the first two buoys and repeat the procedure trying to get the sonar fish closer to the object. With the marker buoy over the spot, it will be easy to maneuver the boat and show the object at short range on the sonar. Do this from different headings to verify the buoy position is over the spot. You may find that the buoy is offset from the spot and you need to throw in another buoy to a closer approximation of the true location.

The buoy method works, but it requires some quick action from your helper while you keep the boat on a steady course and speed. The distance markers on the sonar paper are accurate if your boat speed reading comes from a GPS. The distance traveled from the spot recorded on the paper can be quickly noted at the time the buoy is dropped in. Add the estimated towline length and you will have one side of a right triangle. Another side of the triangle is the sonar range. Simple geometry will give you the heading and distance from the marker buoy to the spot.

If you are searching for a spot in a limited area, you can make a grid of waypoints on the GPS which create search lines covering the area. Depending on the situation, 500 feet apart is a good interval. Maneuver the boat along the lines at an accurate speed until the object is spotted. Create a new waypoint at this location. Note the distance traveled at the moment that the waypoint is created. You can now estimate the GPS location of the object based on the new waypoint location and the

recorded data. You can record this data while you continue searching and the calculation can be done later. Mark the waypoint creation and number on the recording paper with a pen and it will be easy to visualize the situation later. You can see the object on the paper and measure the range and distance traveled using the calibrated markers on the paper. The accuracy depends on the quickness of your helper in recording the data and creating the waypoints. A handheld GPS is nice for creating the waypoints while the boat GPS is used to maintain the correct speed and track.

When setting up search lines, it works best to use true north / south and east / west directions. This makes the calculation of the GPS offsets easy. If you are traveling west, for example, and the sonar shows an object 608 feet away, it is 1/10 degree north of your GPS location. If you are traveling true west your latitude number does not change as you move along. Therefore you already know the latitude of the spot because it is on a parallel line 1/10 degree from your track.

The longitude situation is similar but the distance per degree varies with your position on the globe. Where I live, if I'm traveling north, and the sonar shows an object 499 feet away, it will be 1/10 of a degree east of my GPS location. I know the longitude of the object because it is 1/10 degree parallel to my track.

If you set up search lines on true cardinal headings you can locate any spot easily. Follow a search line until the object is seen on the paper. Record the range and convert it to degrees offset. Create a search track which is 90 degrees from the first track and will bring the boat within sonar range of the same object. Follow this search line until the object is seen again on the paper. Record the range and convert it to degrees offset. Now you can combine the longitude and latitude offsets from your two tracks to derive the GPS location of the object.

Again, the accuracy of this method depends on careful boat handling and recording of data. Since the sonar cannot see straight down, the last part of the search must be done with a combination of geometry and calculation. It is quite easy to do this at your desk at home, but not so easy on a rolling boat with wind blowing you off track. Practice with the GPS so that you can keep the boat exactly on track. Any offset from the track will be added to the error of the final position.

Electronics Technical Information

Specifications

Transmitter Section

Circuit:	Driven push-pull amplifier
Frequency:	24 KHz adjustable
Tuning method:	trim-pot
Pulse width:	1 mS
Peak pulse power:	300 watts RMS
Peak-to-peak volts:	500 volts
Pulse shape:	Square
Output Z:	60 ohms resistive
Trigger:	3 volt positive pulse
Power input:	12 to 20 VDC
Current draw	500 mA

Receiver Section

Circuit:	Two stage tuned amplifier with log detector
Frequency:	24 KHz adjustable
Tuning Method:	Dip Switches
Sensitivity:	50 uV
Gain control	50 DB
Detector dynamic range:	30 DB
Output DC level:	2 V to 8 V adjustable
Output span:	2 V for 30 DB change of input level
Receiver BW	5 KHz @ -6 DB
STC slope:	Adjustable 200 feet to 1200 feet
STC compression:	Zero to > 30 DB
Receiver rise-time:	0.5 mS
Receiver fall-time:	0.75 mS
Range resolution:	15 feet minimum on the 600 foot range 30 feet minimum on the 1200 foot range
Receiver input:	Balanced transformer isolated
Common mode:	30 DB rejection of common mode inputs

Specifications (cont'd)

Transducer

Type:	Linear array
Drivers:	Six Langevin Piezoelectric pn STC-4SS-3528 Sunnytec, Inc.
Electric feed:	Parallel
Length:	15 inches (6 wavelengths)
Beam shape:	Fan
Impedance :	60 ohms with 0.9 mH external series inductor
Static capacitance:	.02 uF
DC resistance:	Open Circuit
Enclosure:	Lexan box .200" thickness
Dimensions:	Length: 15" Width: 3" Height: 3.7"
Sound plate:	Aluminum .125" 6061-T6511

Modified Display

Original Type:	Si-Tex HE-32
Paper type:	4" /100 mm
Long range:	1200 feet
Short range:	600 feet
Transmit interval:	1.66 second (1200 foot range) 0.85 second (600 foot range)
Range calibration:	Marks every 100 feet
Distance calibration:	Marks every 59 or 14 seconds
Paper movement:	0.33 inch / minute (1200 foot range) 0.56 inch / minute (600 foot range)
Trigger pulse output:	5 V pulse 100 uS into 50 ohms
Input range:	3V light trace, 5V dark trace
Power input:	12 VDC 400 mA

Specifications (cont'd)

Fish

Weight:	27 Lbs
Length:	36”
Diameter:	5”
Slot width:	3”
Slot length:	15.25”
Sound plate length:	15”
Drivers:	6 ea
Spacing:	2.3” center-to-center
Lexan window recess:	0.8”
Sound plate thickness:	.125”
Lexan thickness:	.200”
Screw spacing:	1” to 1.25”
Fin material:	.060” un-galvanized steel
Fin size:	6.25” length, 4.25” height
Nose weight:	10 Lbs, 4.35” diameter
Tow cable:	3/16” nylon and 18 gauge heavy duty lamp cord
Tow cable length:	100’ (no limit on length)
Marine sealant:	3M 4000UV (fast cure)
Wood glue	Polyurethane heavy duty construction type
Lexan glue:	IPS Weld-On #16
Paint:	Rust-Oleum oil-based
Wood:	Pine 1 by 6
Eyescrew:	¼ inch by 3 inch stainless steel
Maximum tow speed:	5 Kts

Circuit Description

Transmitter sheet 1

The mono-stable (m/s) circuit of Q1 and Q 2 is triggered by a positive pulse at R1. The period of this circuit is about 60 m S. The second m/s circuit of Q3 and Q 4 is triggered once, at the leading edge of the first m/s circuit, but cannot trigger again until the first m/s circuit times out and resets. The slow recycle time of the m/s circuit prevents rapid triggering of the second m/s circuit. This limits the duty cycle and prevents overload. The second circuit determines the sonar pulse width and is nominally 1 m S. The modulation driver is Q5 which generates a positive pulse. U1 is a 10 V regulator IC.

Transmitter sheet 2

The precision timer U2 is the transmitter frequency source. It operates at double the sonar transmitter frequency. R17 is the frequency adjustment. The flip-flop Q6 and Q7 is a free running square wave generator. It is adjusted to run at a slightly lower frequency than the desired sonar frequency. The pulses from U2 synchronize the flip-flop and force it to operate at the correct frequency. This circuit generates a clean square wave to drive the output stage, The drive signals for the transmitter are taken from points E and D. The transmit sample output is a test point used for monitoring the frequency. U1 is a 10 V regulator IC.

Transmitter sheet 3

U4 is a pulse width modulated voltage regulator. U5 is a FET driver. The power supply generates 14 VDC for the receiver and transmitter board and 30 VDC regulated for the transmitter output stage. T1 is a flyback transformer which delivers positive pulses to the two diodes each time Q8 turns off. The voltage is sensed at the 30 volt line and the current is sensed at R34. The sonar transmits in short pulses and the energy for each transmit burst is stored in the capacitor bank, C11. After the transmit burst, the capacitor is recharged to 30 V by the power supply. R35 limits the maximum current during the recharge time. The operating frequency is about 50 KHz. The power supply is a source of noise and must be isolated from the receiver. Install a metal shield between the transmitter and receiver board. Be sure both boards are well bonded to a ground plane.

Transmitter sheet 4

The FET driver is driven by the square wave at D and E. The two independent channels drive the two FET output transistors. The modulation pulse at B powers the FET driver and thereby activates the output amplifier. The transformer, Q9 and Q10 operate as a push-pull power amplifier. The two networks R36, R37, C13 and C14 are adjusted to prevent high

voltage overshoot in the power amplifier.

The output circuit delivers the transmit pulse to the transducer and directs the receive signal from the transducer to the receiver board. The output stage must be isolated from ground to prevent noise from a ground loop. The sound plate in the fish is electrically connected to the low side of the input connection. This is an effective connection to ground through the water and through the boat grounding system. If any other ground connections are made to the low side of the input line, in the boat, a ground loop will result. The receiver will display noise from the boat engine and electrical system. With the isolated input-output system, no noise will be picked up. The input balance is made as close as possible by selecting C15 to compensate for capacitance to ground in T1. R38 reduces loss of receiver signal across the inductance of T1. It has little effect during transmit, but provides a safety load in case the transmitter is triggered without any transducer connected.

Receiver Sheet 1

The receiver input is isolated by T1. The two stages of amplification are tuned by the dip switch selected capacitors. The value of the capacitors is selected to allow a wide range of tuning. They roughly follow a binary sequence of: 1, 2, 4, 8, 16, etc. The overall range of tuning can be trimmed by changing the value of C2. The two stages have a master gain control, R 12, which varies the bias on both transistors. This is the front panel "gain" control.

The automatic gain control, known as STC, operates by shunting the inductors in the two amplifier stages with FET opto-isolators, U1 and U2. These are controlled by circuitry that varies the shunting effect according to a ramp voltage. When maximum gain is needed, U1 and U2 have no effect in the circuit.

Receiver Sheet 2

Three stages of amplification are connected to detector diodes and separately feed a summing network. As the input signal at B increases, the third stage will saturate first, then the second, and finally the first. This requires about 30 DB of input increase and results in a smooth change of voltage at the output summing network. This greatly increases the dynamic range of the receiver. The sonar signals vary greatly in amplitude and this circuit makes the display much easier to adjust.

The output circuit, U3, tailors the DC level and span of the output signal to the input requirements of the display unit. Adjust the DC level so that the paper will not be shaded with minimum gain settings. When the fish is in the ocean, the ambient noise should shade the paper with moderate gain settings. Adjust the span for the best use of the 30 DB dynamic range between light shading and dark shading. The "receiver sample" is a test point of the 24 KHz signal.

Receiver Sheet 3

The system trigger sets the m/s circuit with a positive input at R37. The purpose of the circuit is to turn on the LED in U6 long enough to discharge C27. This occurs at beginning of the stylus sweep when the transmitter operates. If the slope control is advanced, the integrator circuit will begin to generate a negative

going ramp voltage at pin 6. If the slope control is set to minimum, no ramp will be generated and the voltage at pin 6 will be steady at about 6 V. If the “compression” control is increased the LEDs of U1 and U2 will begin to activate and shunt the inductors in the receiver first and second stages, reducing their gain.

In operation, the “slope’ and “compression” controls are adjusted to control the current in the LEDs and thereby control the gain of the receiver. The trigger pulse resets the system before each stylus sweep and the ramp at pin 6 decreases the current in the LEDs over a period of time. The “compression” setting controls the initial gain reduction which will decrease with the ramp voltage. The rate and amount of gain change is widely adjustable to accommodate different situations.

Motor Sheet 1

The motor used in the SI-Tex unit has a tachometer output which is an AC voltage proportional to speed. The tachometer output is applied to the bias network and U1A input. The output is a square wave at pin 1. The bias network ensures that the output at pin 1 will remain high when no signal is present. The pulse generator, Q1, generates a constant pulse width signal at each negative going transition from U1A.

Motor Sheet 2

The paper roll motor is controlled by a variable voltage regulator IC. The two trim-pots are set to give the necessary voltage and motor speed for the two sonar ranges. The motor speed is not critical and not feedback system is necessary.

Motor Sheet 3

The constant pulse width pulses are applied to D4 at B. Each pulse increases the charge on C4 while R13 slowly decreases the charge. A saw tooth waveform is produced across C4 and at the input of U1B. The DC level at pin 5 sets the point on the saw tooth waveform where the comparator output switches. This results in a variable pulse width at the output of U1B which is dependent on the motor speed.

The variable pulse width output at pin 7 is somewhat integrated by C8 and C9 and applied to the gate of Q2. The motor speed is controlled by the current through Q2. When the circuit starts, the output of U1B is fully positive and Q2 is biased on. When the motor reaches the programmed speed, the saw tooth waveform will build up at the input of U1B and cause a reduction of the duty cycle at the output of U1B. The voltage at pin 5 is the motor speed program voltage. Two trim-pots set the motor speed for two sonar ranges.

The current limit circuit controls the maximum current in the motor. If the current through the motor becomes excessive, the voltage across R19 will bias Q3 on, and decrease the bias to Q2 via D1. This will limit the motor current to a safe maximum.

Stylus Sheet 1

The stylus requires a high voltage, high frequency, writing voltage to mark the paper. This voltage is controlled or modulated by the output of the receiver. The writing density, on the paper, seems to be roughly proportional to the power of the applied signal.

The inputs to the stylus board are combined

at Q1. The receiver output, range marks, and distance marks are applied to the level translator circuit of Q1. The output voltage of the Q1 circuit is chopped by Q2 at an 18 KHz rate. This pulsed waveform is normally below the threshold of biasing Q3 into conduction. The bias control sets this quiescent level. When an input signal is amplified by Q1 the chopped waveform will cause Q3 to drive T1 with a pulsed current. The flyback voltage is stepped up to the required level to write on the paper. The power of the stylus writing voltage is proportional to the height of the drive pulses going to Q3.

Since the stylus system is DC coupled, a current limiter circuit is provided to prevent excessive burning of the paper when strong sustained inputs are present. This happens when the gain control is turned up too high or when the DC level is not correct.

When the voltage across R12 reaches the maximum safe level, the LED section of U1 is activated. The transistor section of U1 conducts and limits the drive to Q3. In this way the current is limited in the output circuit. C5 allows the circuit to deliver strong short pulses of writing current, but sustained overload will be limited.

Calibration Sheet 1

The reed switch is the source of the transmitter synchronization in the fish finder. The closing reed switch triggers the m/s circuit of Q1 and Q2. The period of the m/s circuit is long enough to eliminate possible multiple triggering from contact bounce. Q3, Q5, and Q4 generate and amplify a short pulse for the system trigger. Q4 is a current limit circuit to prevent damage if the trigger output is shorted.

The positive pulse at Q3 is conducted to the m/s circuit of Q6 and Q7 via the gate circuit of Q8. When Q8 is not biased on, the pulse from Q3 will trigger the m/s circuit. The m/s circuit is used to control the distance mark dot generator and allow it to remain on through one sweep of the stylus. When the system trigger occurs and if the gate is open, the m/s circuit sets for the time of one sweep. When the m/s circuit returns to its quiescent state, a negative going pulse is generated and transmitted to the flip flop of Q9 and Q10 on sheet 2. This pulse resets the flip flop and closes the gate circuit of Q8. Trigger pulses will not pass Q8 until the flip flop is again set by the time base 14 or 59 seconds. In this way, one line of dots will be printed every 14 or 59 seconds.

The output at D is a variable negative going pulse coincident with the trigger pulse.

Calibration Sheet 2

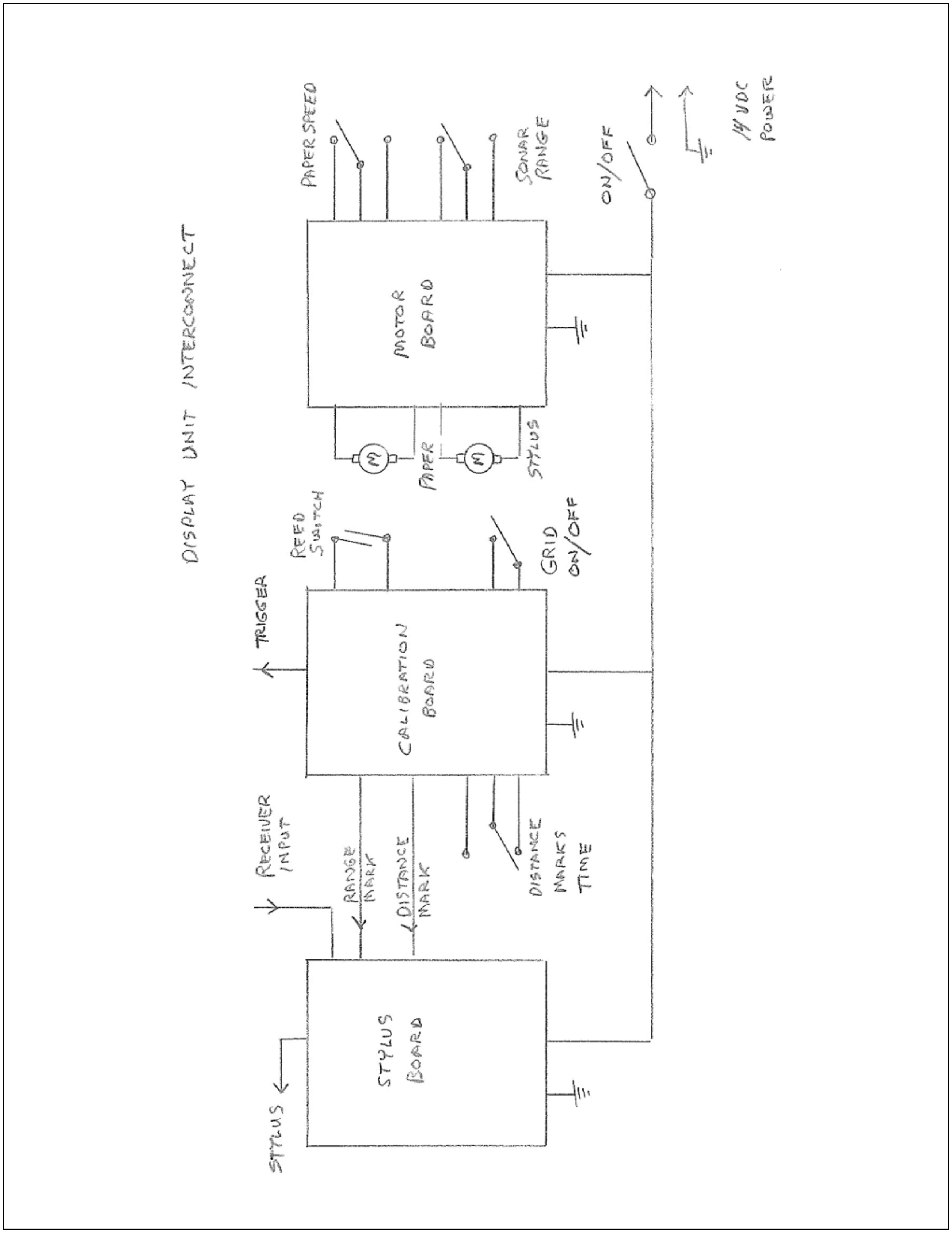
The timer U1 generates two time base frequencies which are selected by the front panel switch. These control the 14 or 59 seconds time interval of the distance marks. The output frequency of U1 is divided by 10,000 and used to set the flip flop of Q9 and Q10. Every 14 or 59 seconds the flip flop is set and waits for a reset signal at B. The output is a low signal at A when the flip flop is set.

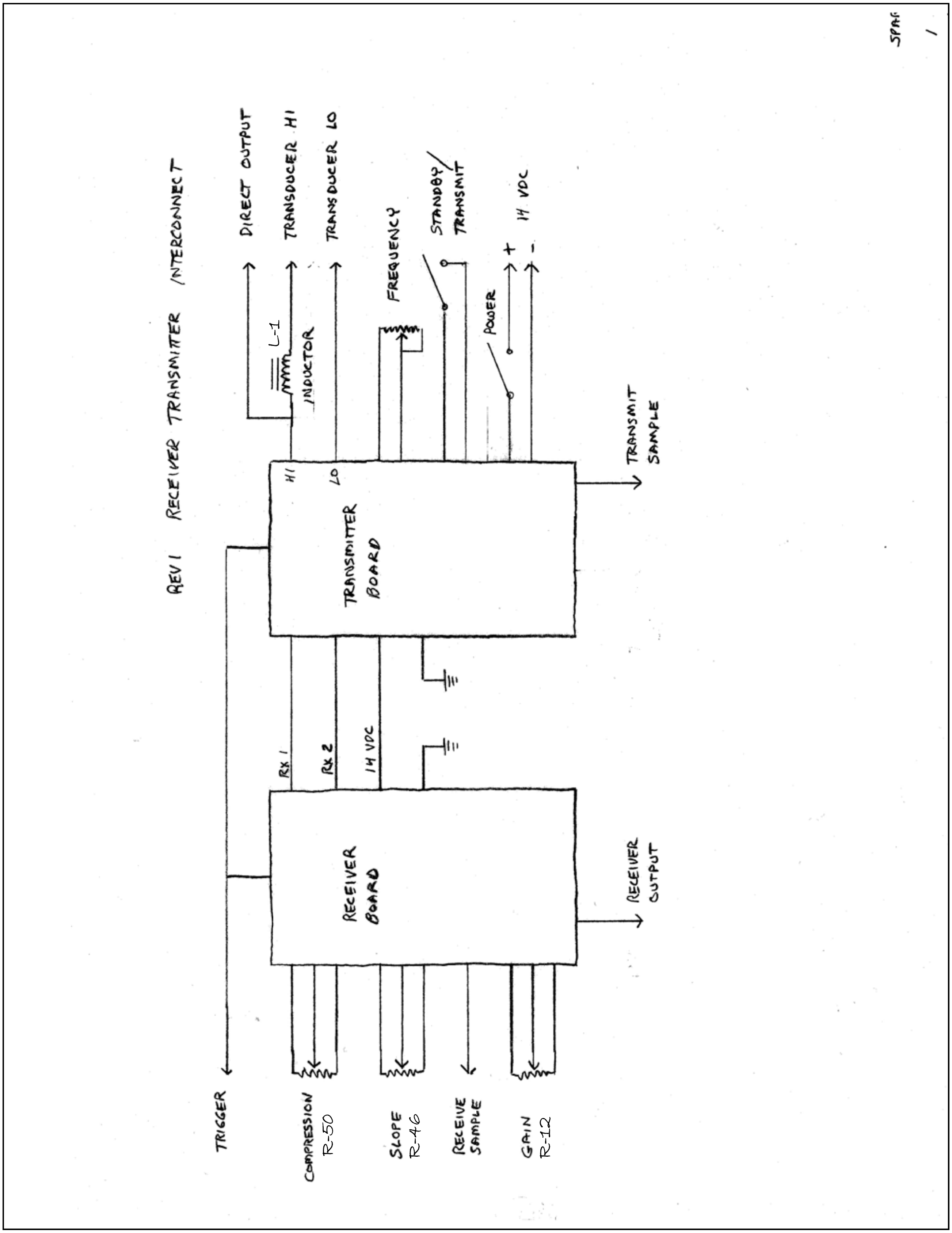
Calibration Sheet 3

The timer, U6, generates the range marks. These are the 20.4 m S spaced dots that print on the paper during each sweep. To synchronize the dots, the negative going pulse at D momentarily holds the voltage of C19 low and

then allows the circuit to run normally until the next trigger pulse. In this way, the timer is always started at the beginning of each sweep. The 20.4 m S time period is equivalent to 100 feet of sonar range.

The timer U7 generates a series of pulses that appear as a line of dots printed vertically on the paper to form distance marks. When the input at C is high the dots are generated. The three 10 volt regulator ICs are use to ensure isolation between the different pulse circuits on the calibration card.


DISPLAY UNIT INTERCONNECT
PAPER SPEED
SONAR RANGE
ON/OFF
14 VDC POWER
MOTOR BOARD
PAPER
STYLUS
REED SWITCH
GRID ON/OFF
TRIGGER
CALIBRATION BOARD
RECEIVER INPUT
RANGE MARK
DISTANCE MARK
DISTANCE MARKS TIME
STYLUS BOARD
STYLUS



REV I RECEIVER TRANSMITTER INTERCONNECT
DIRECT OUTPUT
TRANSDUCER HI
TRANSDUCER LO
L-1
INDUCTOR
FREQUENCY
STANDBY/TRANSMIT
POWER
+
-
14 VDC
HI
LO
TRANSMITTER BOARD
TRANSMIT SAMPLE
RX 1
RX 2
14 VDC
RECEIVER BOARD
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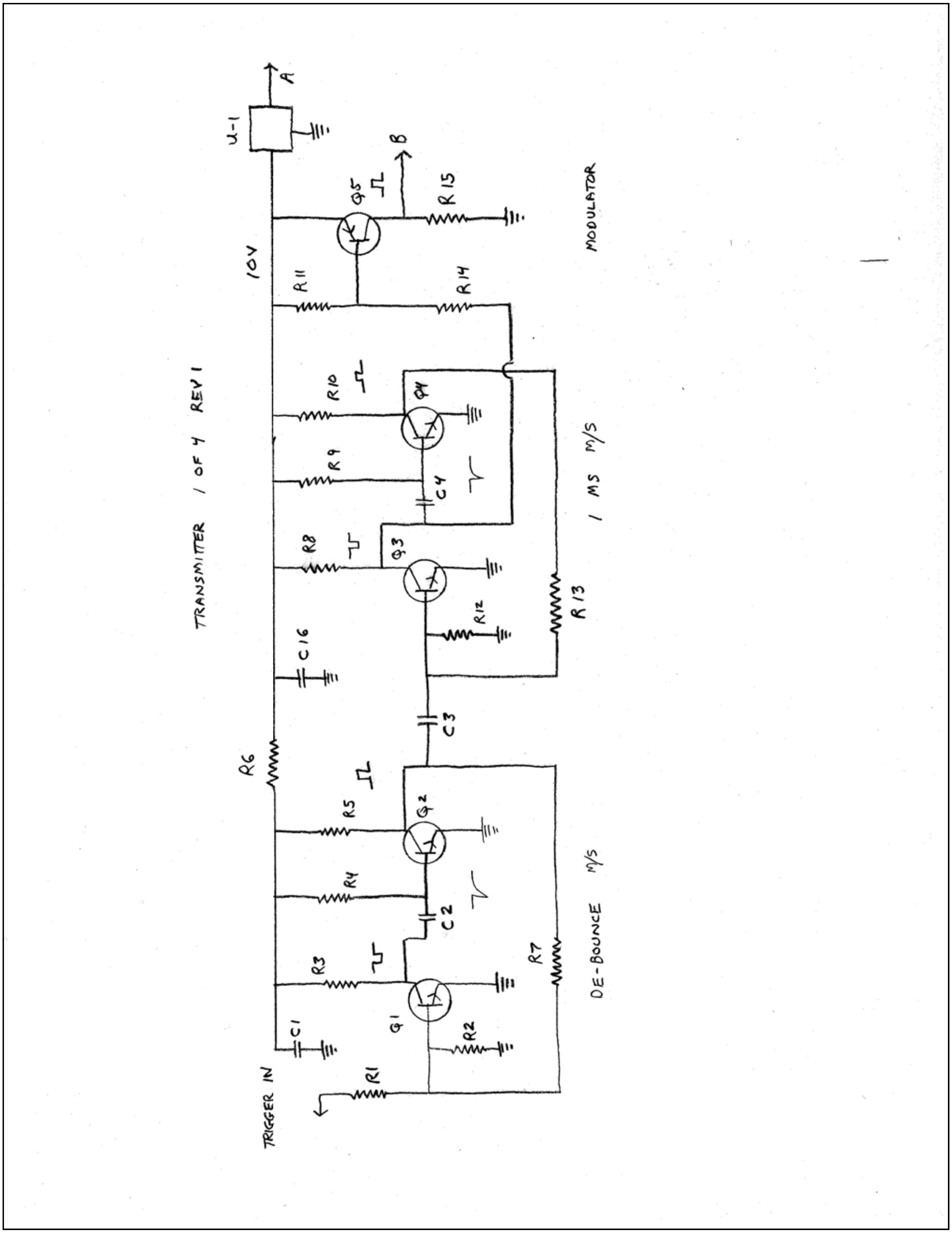
TRIGGER
COMPRESSION R-50
SLOPE R-46
RECEIVE SAMPLE
GAIN R-12


TRANSMITTER 1 OF 4 REV 1
TRIGGER IN
DE-BOUNCE M/S
1 MS M/S
MODULATOR
10V
U-1
A
B
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
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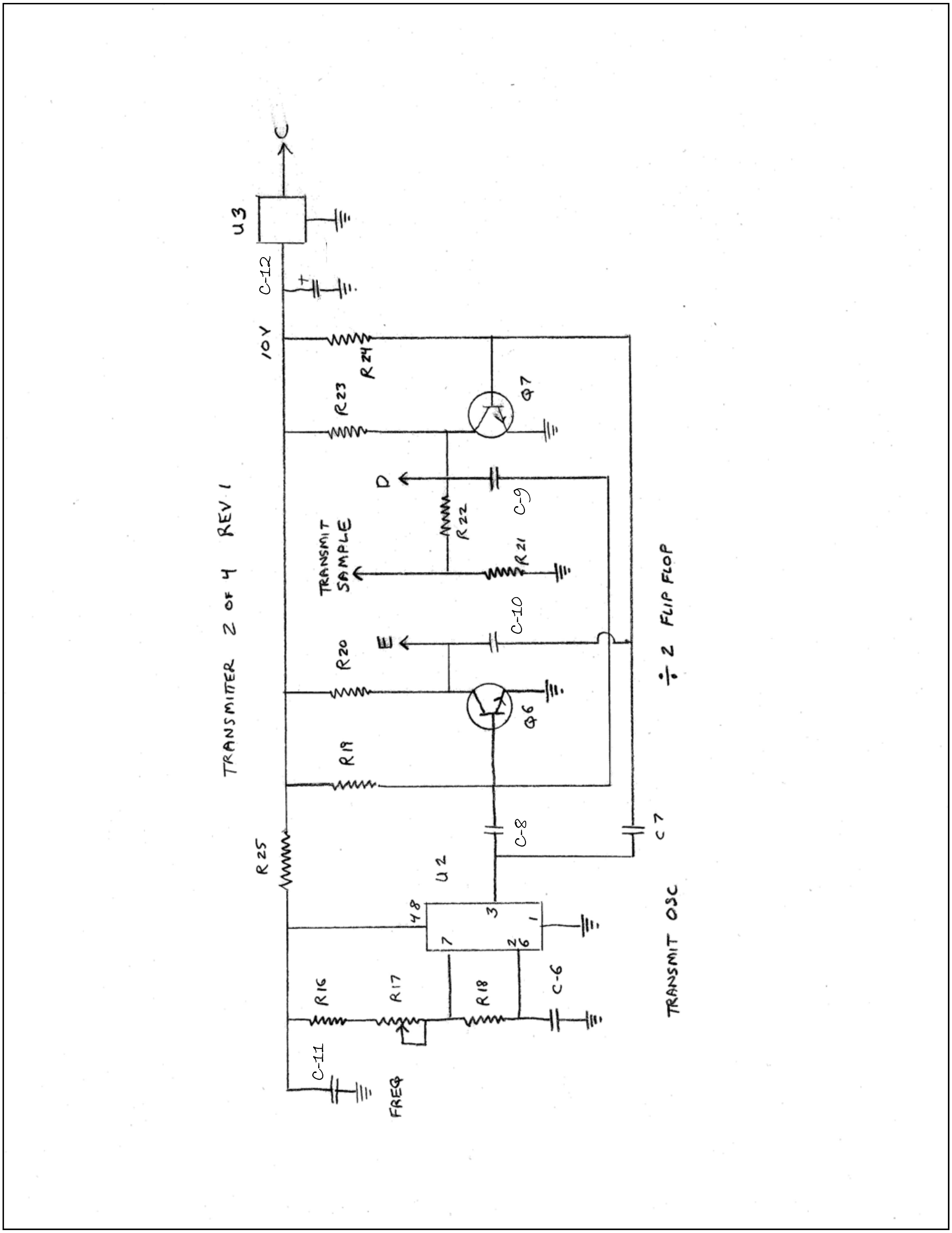
Q2
Q3
Q4
Q5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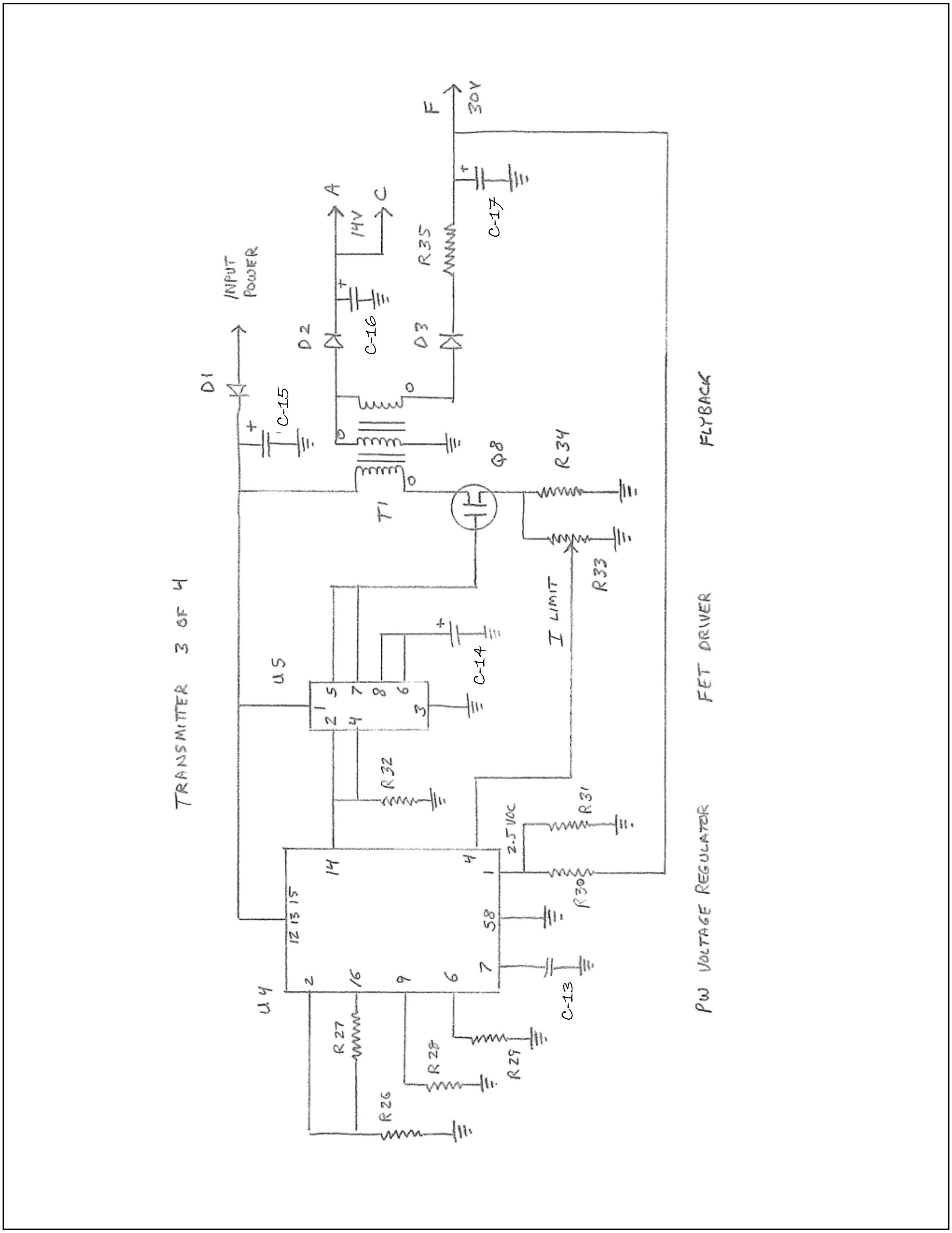
U3
C
C-12
10V
R24
R23
Q7
D
R22
C-9
TRANSMIT SAMPLE
R21
C-10
E
R20
Q6
R19
÷ 2 FLIP FLOP
C-8
C 7
R25
U2
4 8
3
1
7
2 6
R16
R17
R18
C-6
C-11
FREQ
TRANSMIT OSC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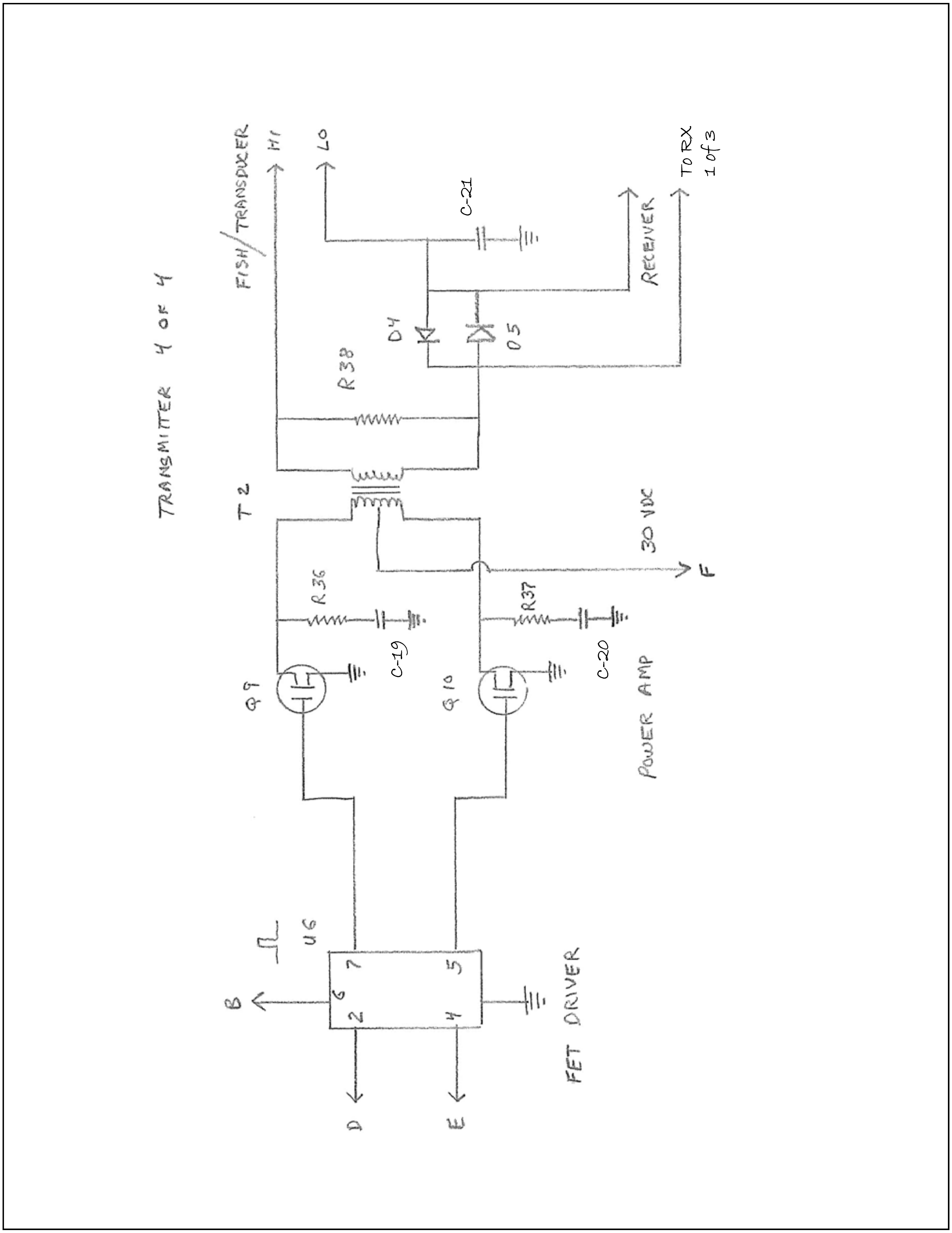
INPUT POWER
D1
C-15
D2
C-16
A
14V
C
D3
R35
C-17
F
30V
T1
Q8
R34
R33
I LIMIT
U5
C-14
R32
U4
R26
R27
R28
R29
C-13
R30
R31
2.5 VDC
PW VOLTAGE REGULATOR
FET DRIVER
FLYBACK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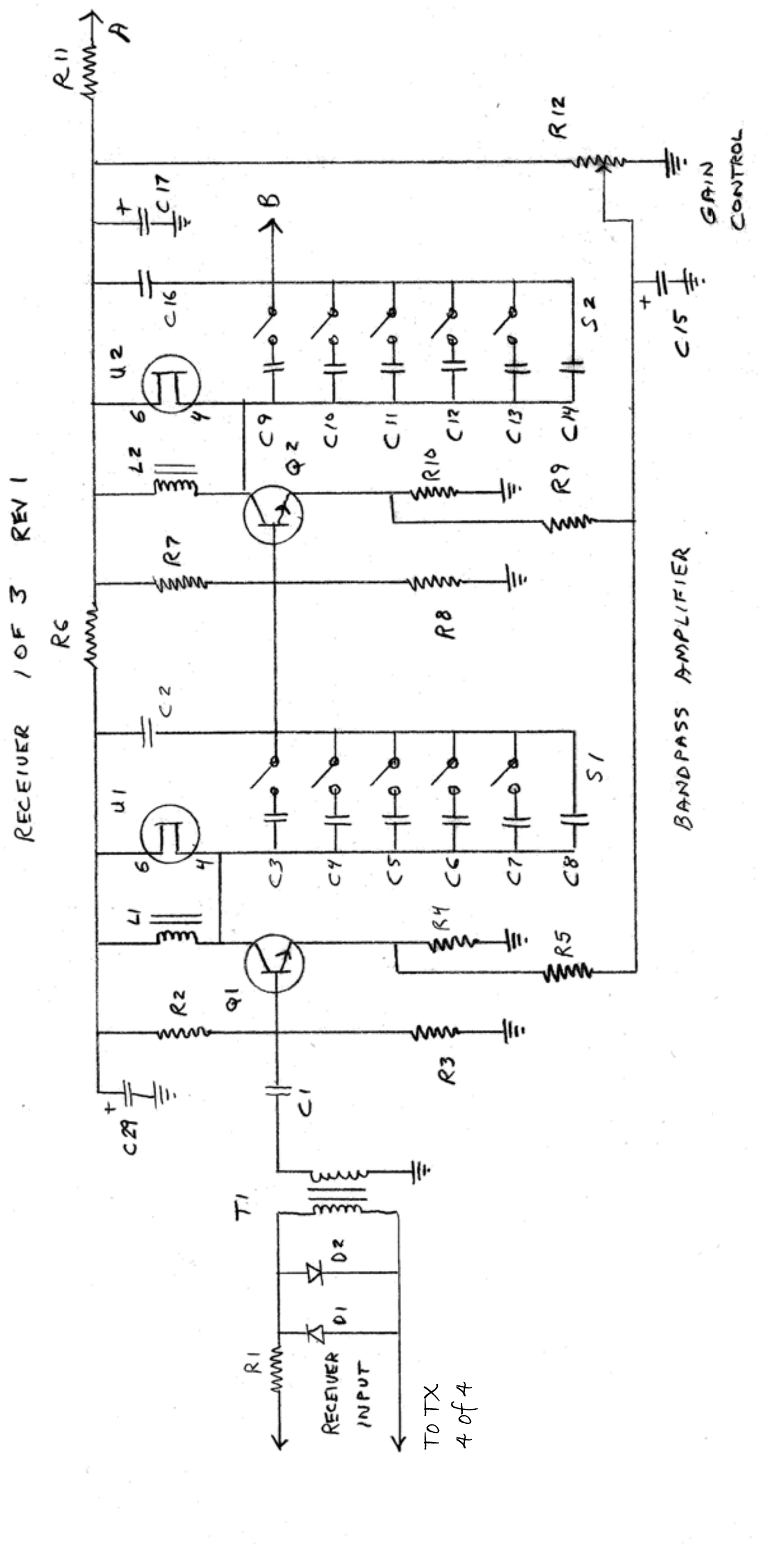
FISH/TRANSDUCER
HI
LO
C-21
RECEIVER
TO RX
1 of 3
D4
D5
R38
T2
30 VDC
F
R36
R37
C-19
C-20
Q9
Q10
POWER AMP
U6
B
D
E
FET DRIVER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BANDPASS AMPLIFIER
GAIN CONTROL
RECEIVER INPUT
TO TX 4 of 4
R1
D1
D2
T1
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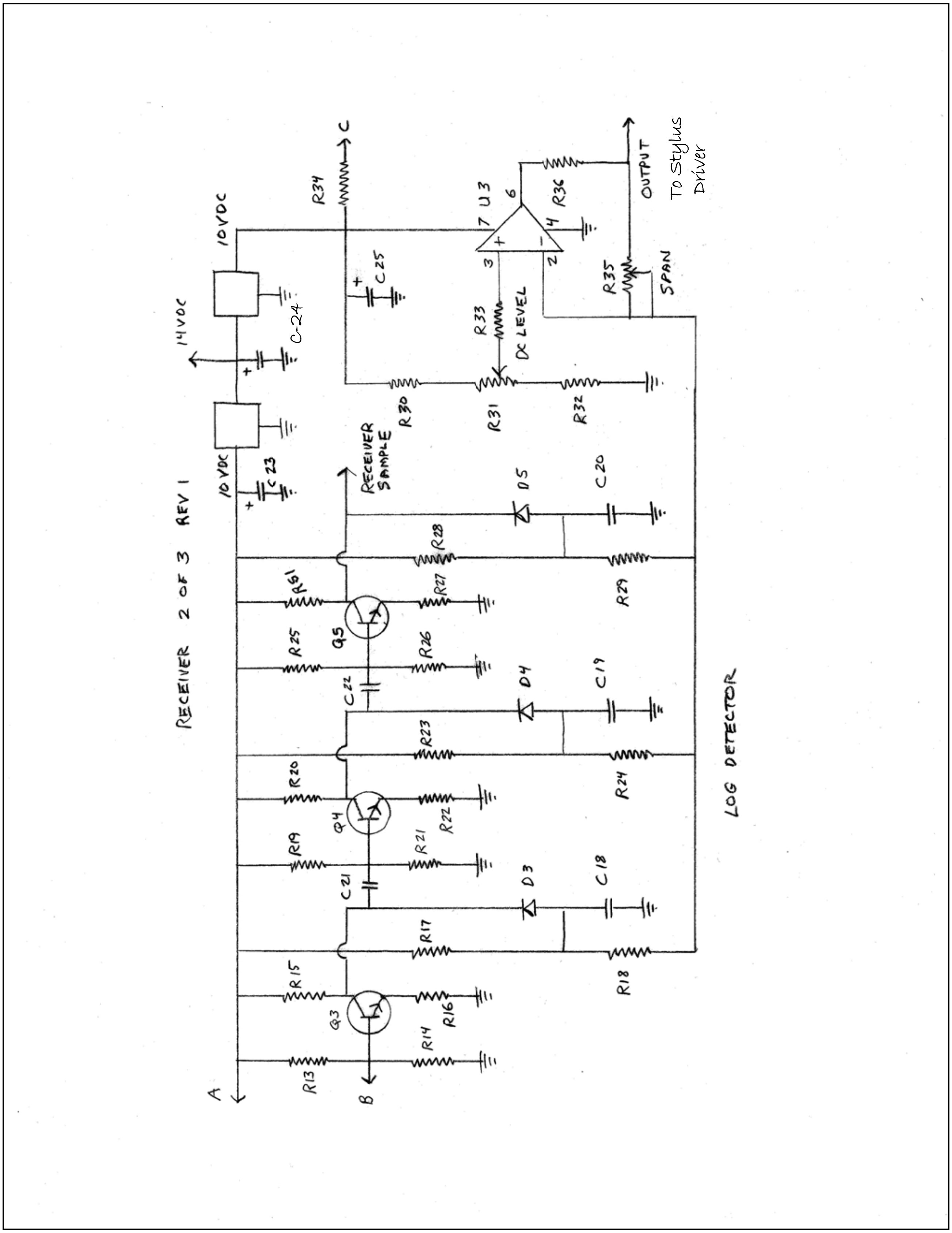
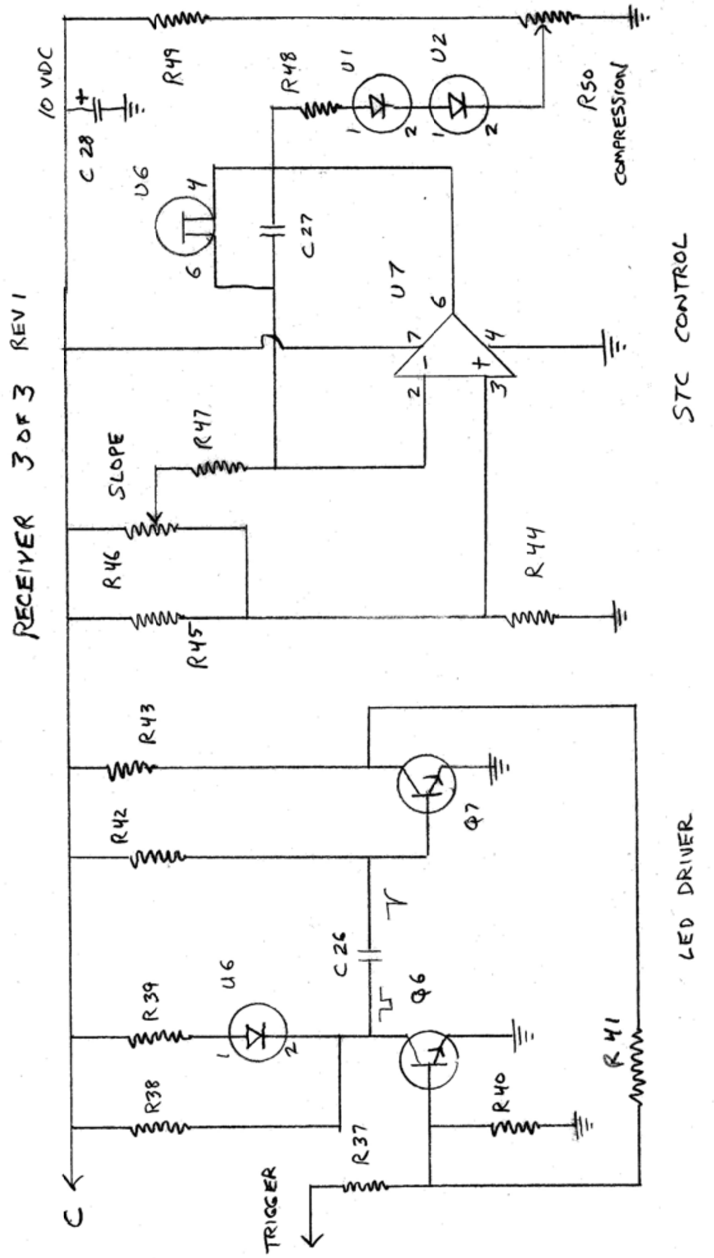
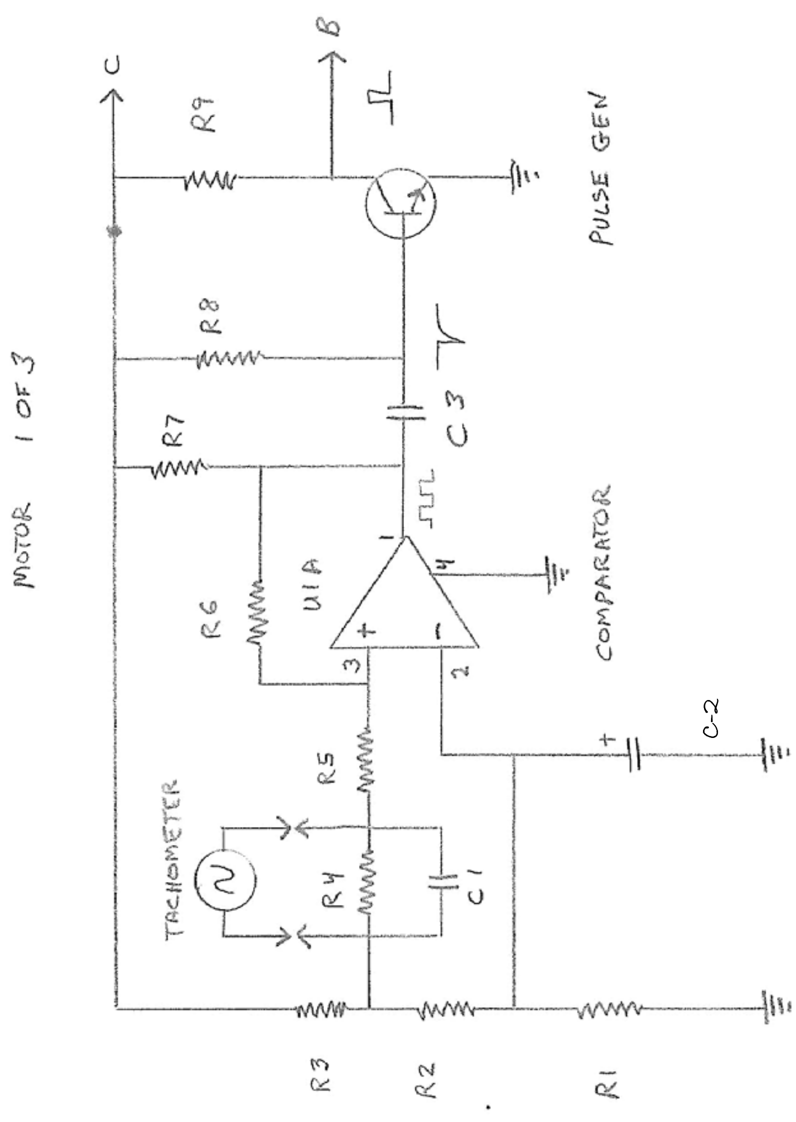
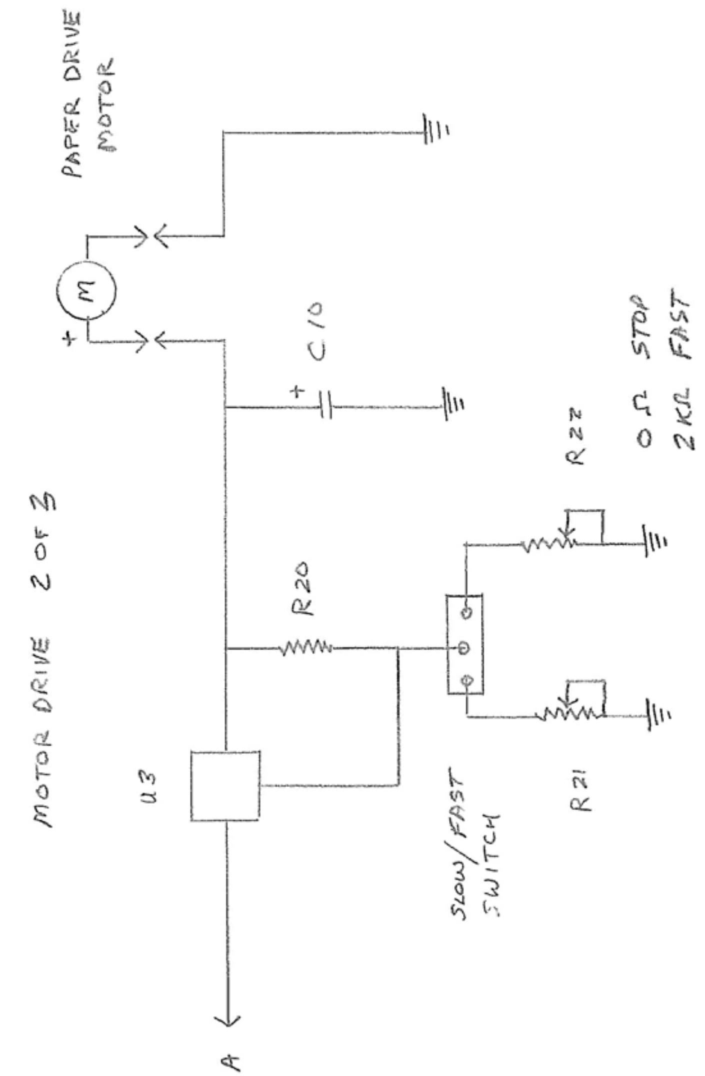
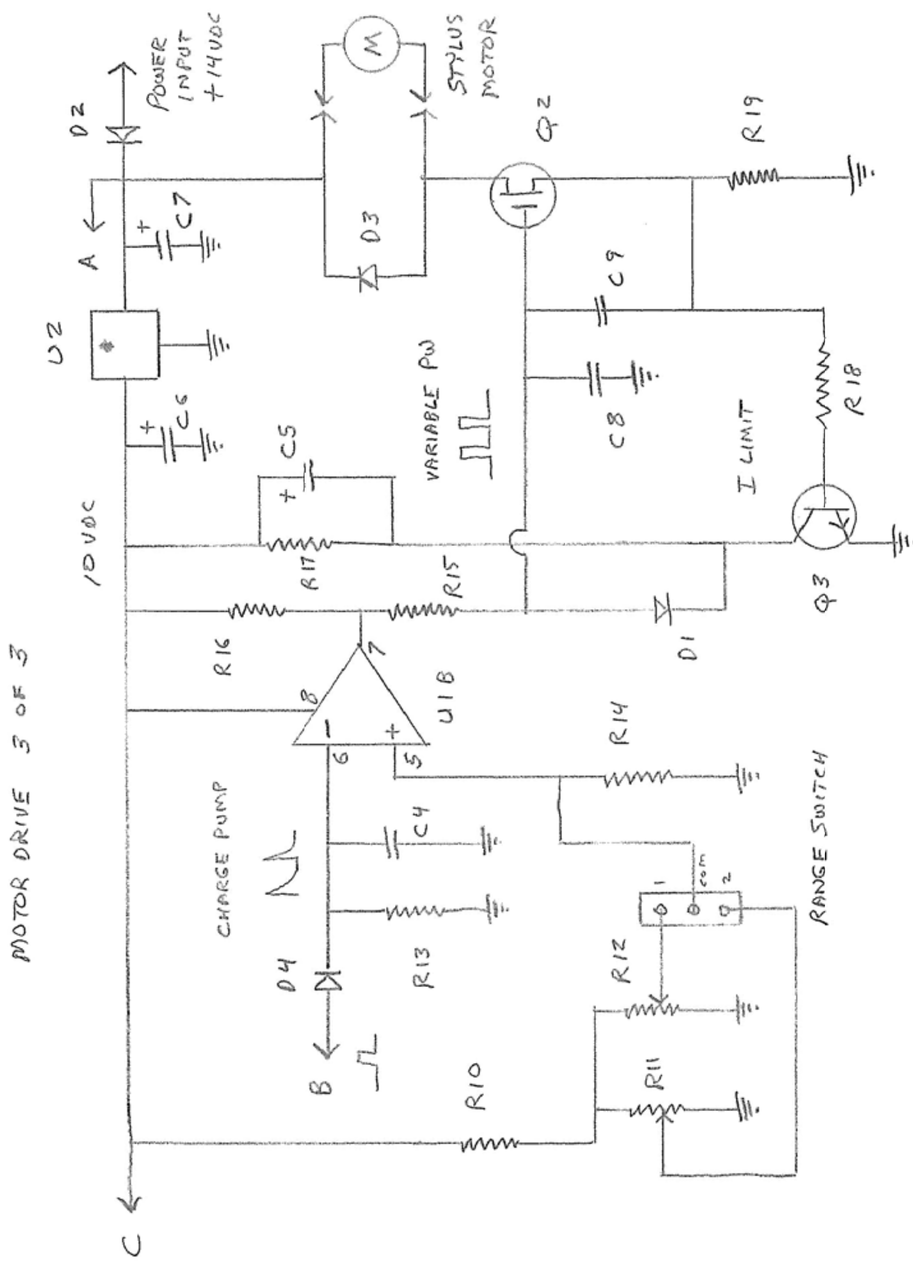
R3
R2
Q1
L1
R4
R5
U1
C3
C4
C5
C6
C7
C8
S1
C2
R6
R7
R8
L2
Q2
R10
R9
U2
C9
C10
C11
C12
C13
C14
S2
C16
C17
C15
B
R12
R11
A

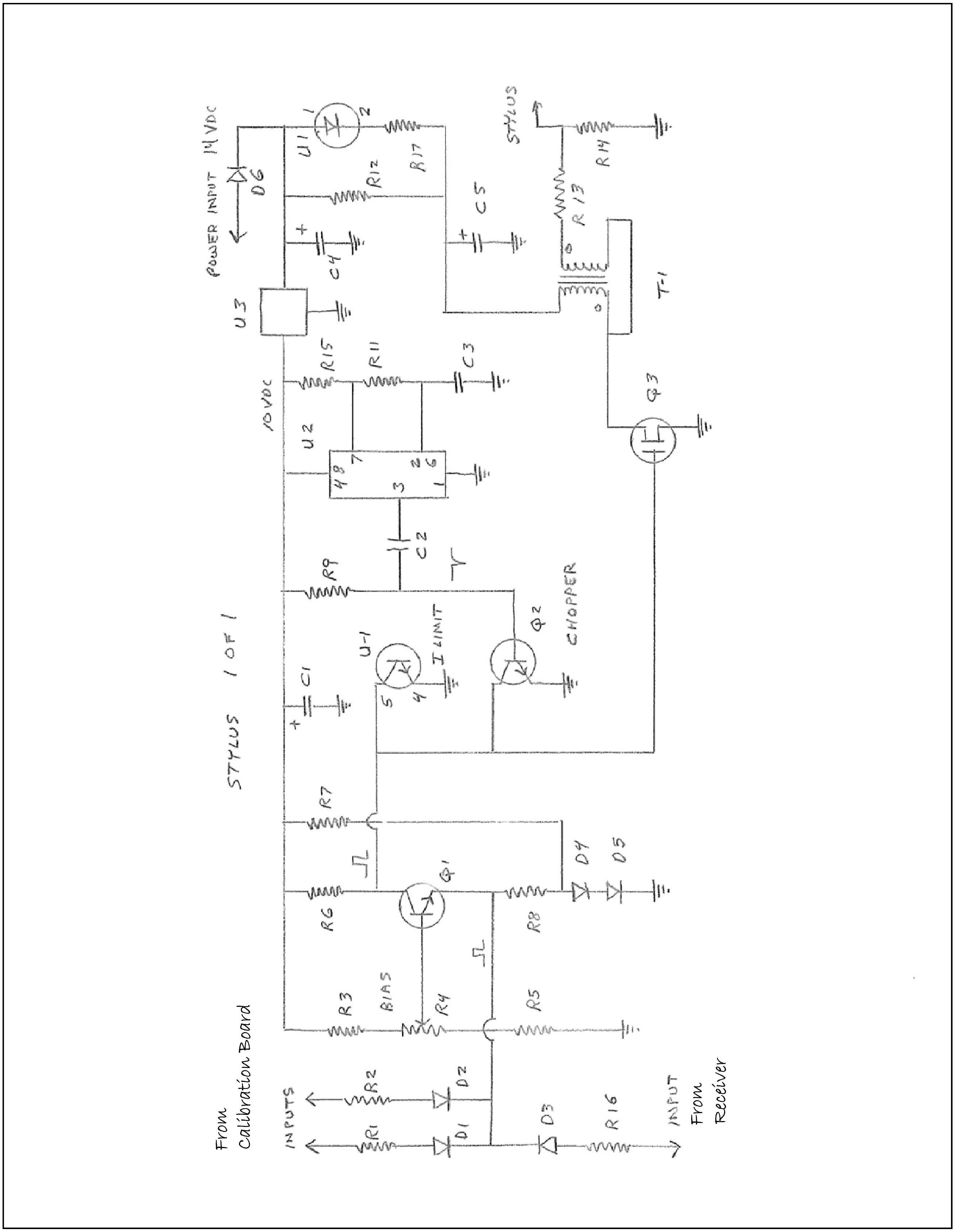

RECEIVER 2 OF 3 REV 1
LOG DETECTOR
To Stylus Driver
OUTPUT
SPAN
DC LEVEL
RECEIVER SAMPLE
14VDC
10VDC
10VDC
C-24
C23
C25
U3
R34
R36
R35
R33
R30
R31
R32
D5
C20
R28
R29
R51
R27
Q5
R25
R26
C22
D4
C19
R23
R24
R20
Q4
R22
R19
R21
C21
D3
C18
R17
R18
R15
Q3
R16
R14
R13
A
B
C

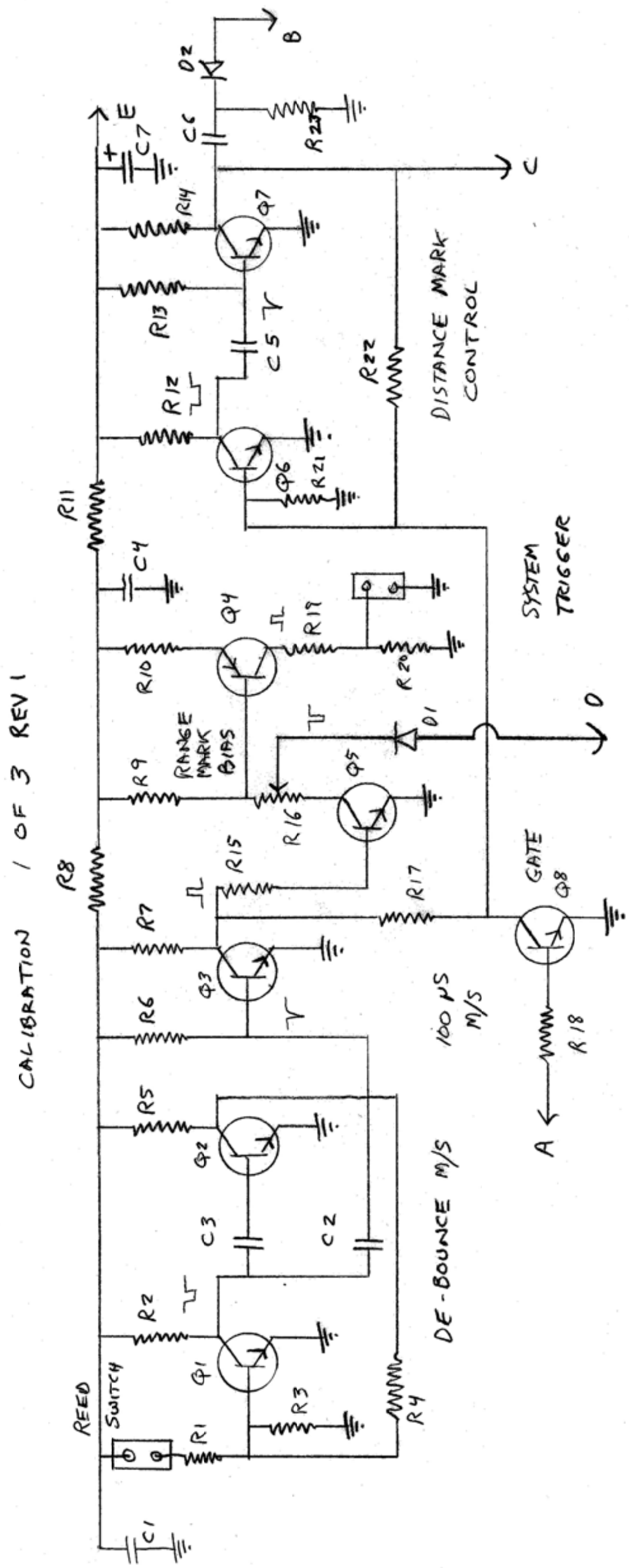

RECEIVER 3 OF 3 REV 1
STC CONTROL
LED DRIVER
SLOPE
COMPRESSION
TRIGGER
10 VDC
C
R49
R48
R50
R47
R46
R45
R44
R43
R42
R41
R40
R39
R38
R37
C28
C27
C26
U1
U2
U6
U7
Q6
Q7

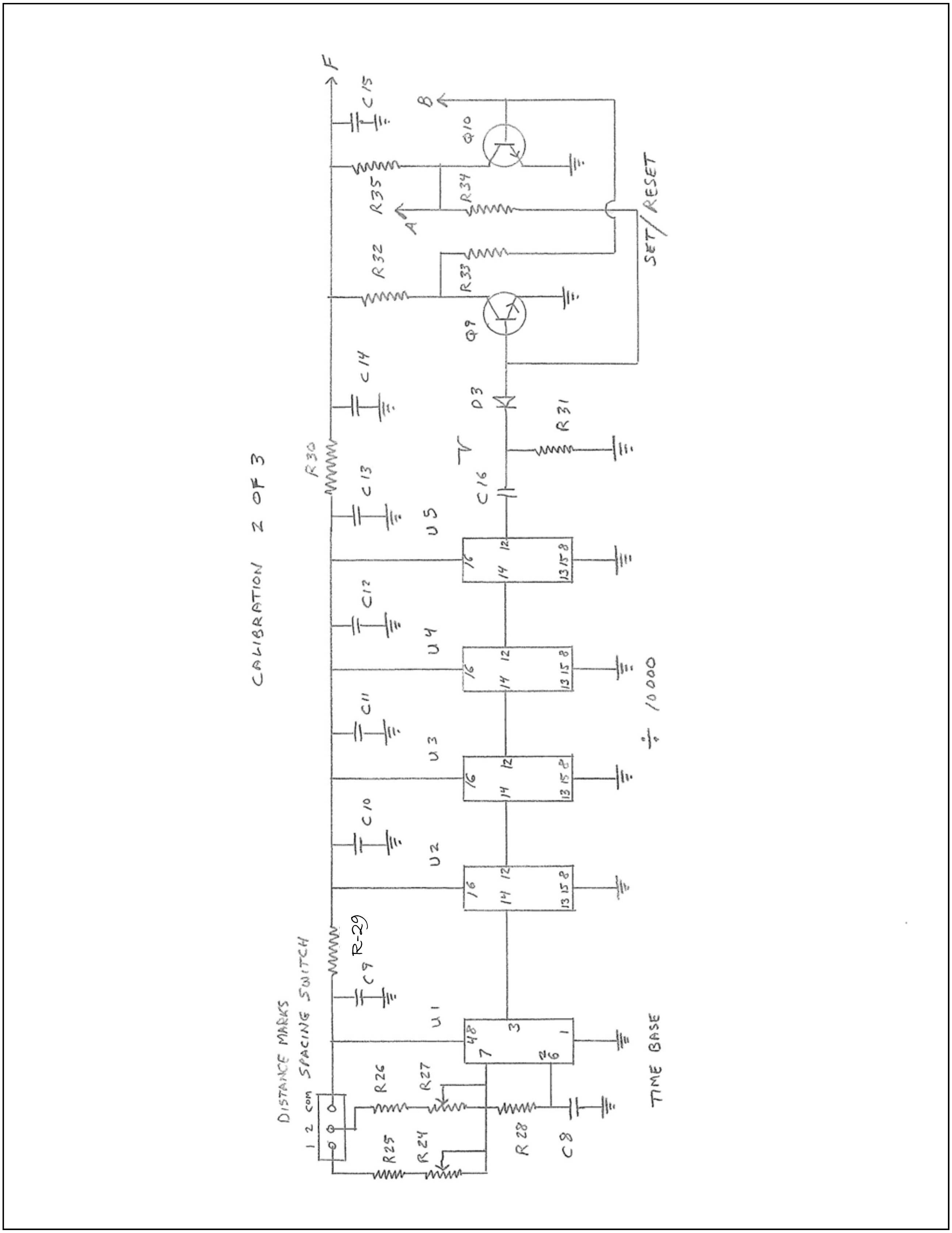

MOTOR 1 OF 3
TACHOMETER
R1
R2
R3
R4
C1
R5
C-2
R6
U1A
COMPARATOR
R7
C3
R8
R9
PULSE GEN
B
C

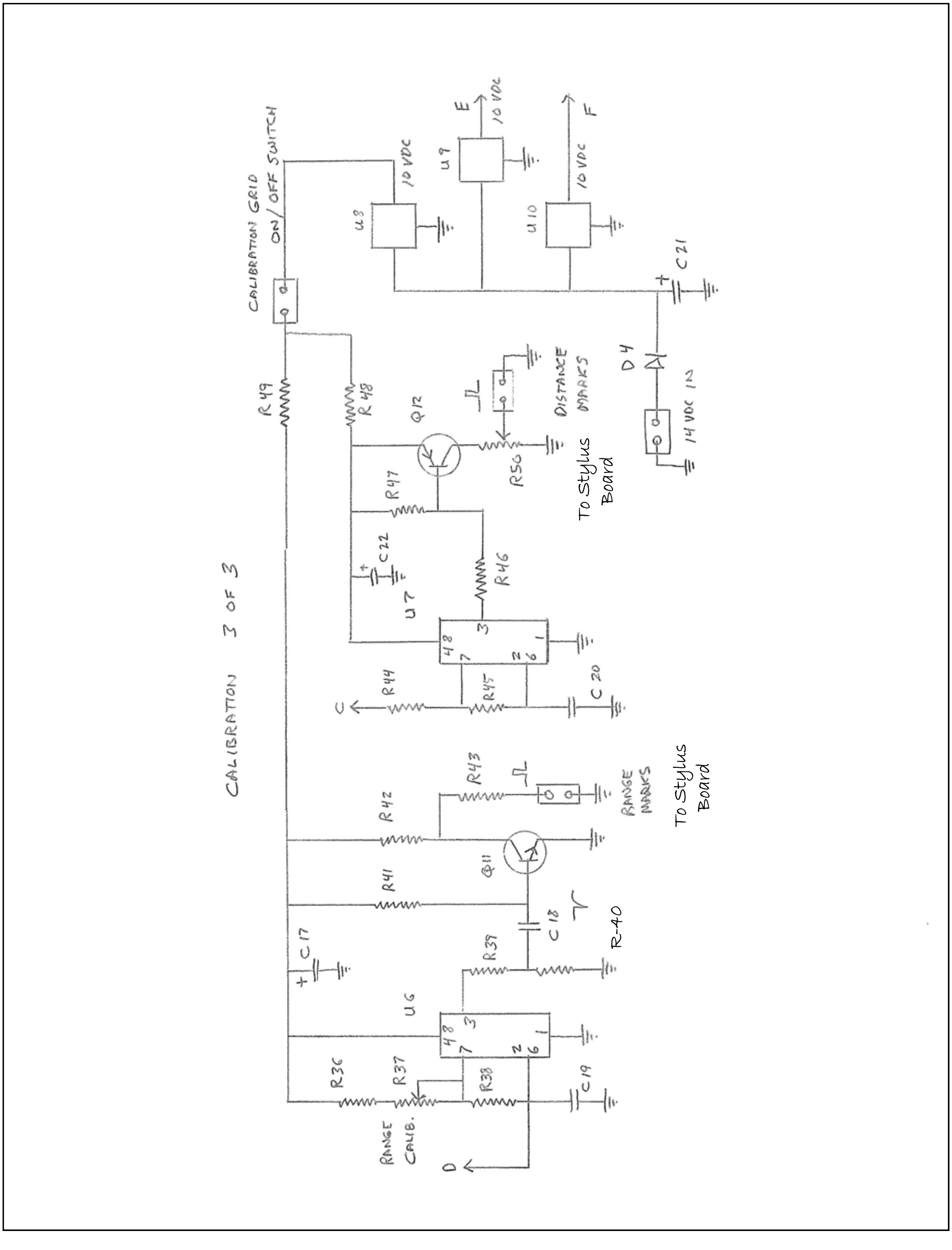

PAPER DRIVE MOTOR
M
+
C10
+
MOTOR DRIVE 2 OF 3
R20
U3
SLOW/FAST SWITCH
R21
R22
0 Ω STOP
2 KΩ FAST
A


MOTOR DRIVE 3 OF 3
POWER INPUT +14VDC
D2
A
C7
U2
C6
10 VDC
M
STYLUS MOTOR
D3
Q2
R19
C9
C8
R18
I LIMIT
Q3
VARIABLE PW
C5
R17
R15
R16
D1
U1B
R14
CHARGE PUMP
C4
R13
D4
B
RANGE SWITCH
com
R12
R11
R10
C


POWER INPUT 14 VDC
D6
U1
R12
R17
C4
C5
U3
STYLUS
R14
R13
T-1
10VDC
R15
R11
C3
U2
Q3
C2
R9
STYLUS 1 OF 1
C1
U-1
I LIMIT
Q2
CHOPPER
R7
Q1
R6
D4
D5
R8
R3
BIAS
R4
R5
From Calibration Board
INPUTS
R1
R2
D1
D2
D3
R16
INPUT From Receiver


CALIBRATION 1 OF 3 REV 1
DE-BOUNCE M/S
100 µS M/S
RANGE MARK BIAS
SYSTEM TRIGGER
DISTANCE MARK CONTROL
GATE
REED SWITCH
C1 C2 C3 C4 C5 C6 C7
R1 R2 R3 R4 R5 R6 R7 R8 R9 R10 R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R23
Q1 Q2 Q3 Q4 Q5 Q6 Q7 Q8
D1 D2
A
B
C
D
E


CALIBRATION 2 OF 3
DISTANCE MARKS
SPACING SWITCH
1 2 COM
TIME BASE
SET/RESET
÷ 10000
U1
U2
U3
U4
U5
R24
R25
R26
R27
R28
R-29
R30
R31
R32
R33
R34
R35
C8
C9
C10
C11
C12
C13
C14
C15
C16
D3
Q9
Q10
A
B
F


CALIBRATION 3 OF 3
CALIBRATION GRID ON/OFF SWITCH
U8
U9
U10
10 VDC
10 VDC
10 VDC
E
F
C21
D4
14 VDC IN
DISTANCE MARKS
To Stylus Board
R49
R48
Q12
R56
R47
C22
R46
U7
R44
R45
C20
C
R43
R42
RANGE MARKS
To Stylus Board
Q11
R41
C18
R-40
R39
C17
U6
R36
R37
R38
C19
RANGE CALIB.
D

Parts List with Notes

Interconnect diagram:

L-1 is 14 turns of # 22 enamel wire on an Amidon Associates Inc E-core set part number EA 77-500. This inductor must be insulated to withstand 300 V to ground.

Controls: R-50, R-46, R-12, and R-17 are extended from the circuit cards to the front panel.

"Trigger", "receiver out", RX sample", and "TX sample" are brought out to BNC connectors on the front panel.

"Direct out", and "Transducer HI and LO" are brought out to banana jacks on the front panel

Parts list:

R-12	10 K Linear Pot	(Gain)
R-17	10K Linear Pot	(Frequency)
R-46	50K Linear Pot	(Slope)
R-50	10 K Linear Pot	(Compression)
L-1	1.0 mH	

Receiver #1

T-1 is part number TL023R miniature audio transformer, 300 ohm primary, 600 ohm secondary. Source is Mouser Electronics.

L-1 and L-2 are Bourns 15 mH RF choke part number 70F152AI-RC. Do not substitute. Source is Mouser Electronics and others.

C-2 and C-16 can be selected to achieve the correct tuning range.

U-1 and U-2 are FET opto-couplers, Fairchild part number H11F2. Do not substitute. Source is Newark Electronics, and others.

Parts List:

R-1	51 ohm	R-7	39 K
R-2	39 K	R-8	3 K
R-3	3 K	R-9	5.6 K
R-4	240 ohm	R-10	240 ohm
R-5	5.6 K	R-11	10 ohm
R-6	10 ohm	R-12	10 K pot

Receiver #1 (cont'd)

C-1	.15 uF	D-1	1N4148
C-2	8200 pF	D-2	1N4148
C-3	150 pF		
C-4	330 pF	T-1	TL023R
C-5	680 pF		
C-6	1200 pF	Q-1	2N4401
C-7	2200 pF	Q-2	2N4401
C-8	2200 pF		
C-9	150 pF	U-1	H11F2
C-10	330 pF	U-2	H11F2
C-11	680 pF		
C-12	1200 pF	L-1	15 mH RFC
C-13	2200 pF	L-2	15 mH RFC
C-14	2200 pF		
C-15	10 uF 16 V		
C-16	8200 pF		
C-17	100 uF 16V		
C-29	100 uF 16V		

Receiver #2

The quiescent voltage on the collectors of Q3, Q4, and Q5 should be 9.5 VDC. Adjust the bias values if necessary.

R32 is selected, if necessary, to set the correct output dc level range of adjustment.

"Receiver sample" goes to the front panel BNC connector. This is a linear output from the receiver.

Parts List:

R-13	51 K	R-26	3.9 K
R-14	3.9 K	R-27	100 ohm
R-15	910 ohm	R-28	160 K
R-16	100 ohm	R-29	430 K
R-17	160 K	R-30	1.6 K
R-18	430 K	R-31	10 K Trimpot
R-19	51 K	R-32	1 K
R-20	910 ohm	R-33	20 K
R-21	3.9 K	R-34	10 ohm
R-22	100 ohm	R-35	100 K Trimpot
R-23	160 K	R-36	100 ohm
R-24	430 K	R-51	910 ohm
R-25	51 K		

Receiver #2 (cont'd)

C-18	2200 pF	Q-3	2N4401
C-19	2200 pF	Q-4	2N4401
C-20	2200 pF	Q-5	2N4401
C-21	1000 pF		
C-22	1000 pF	U-3	LF-411CN
C-23	100 uF 16 V	U-4	78L10AC
C-24	100 uF 16 V	U-5	78L10AC
C-25	100 uF 16 V		
D-3	1N4148		
D-4	1N4148		
D-5	1N4148		

Receiver #3

R-42 is selected, if necessary, for a pulse width of 6 mS.

U-6 is Fairchild part number H11F2. Do not substitute.

U-7, pin 3, voltage is 6.2 VDC.

Parts List:

R-37	3 K		
R-38	1 K	C-26	.1 uF
R-39	650 ohm	C-27	.47 uF
R40	3.3 K	C-28	100 uF 16 V
R-41	10 K		
R-42	100 K	U-6	H11F2
R-43	910 ohm	U-7	LF411CN
R-44	3.6 K		
R-45	2.2 K	Q-6	2N4401
R-46	50 K Pot (Slope Control)	Q-7	2N4401
R-47	200 K		
R-48	2.2 K		
R-49	6.2 K		
R-50	10 K Pot (Compression Control)		

Transmitter #1

The pulse width at Q-2 is 60 mS.

The pulse width at Q-4 is 1 mS. This circuit generates the transmitter pulse width. Select R-9 to adjust the pulse width.

Parts List:

R-1	5.1 K		
R-2	1.2 K	C-1	100 uF 16 V
R-3	750 ohm	C-2	.82 uF
R-4	110 K	C-3	2200 pF
R-5	750 ohm	C-4	.012 uF
R-6	10 ohm	C-16	100 uF 16V
R-7	9.1 K		
R-8	430 ohm	Q-1	2N4401
R-9	110 K	Q-2	2N4401
R-10	1.2 K	Q-3	2N4401
R-11	5.1 K	Q-4	2N4401
R-12	4.7 K	Q-5	2N4403
R-13	22 K		
R-14	10 K	U-1	78L10AC
R-15	100 ohm		

Transmitter #2

Select R-16 for a frequency at pin 3 of U-2 which is double the desired transmitter frequency. The trim-pot should cover the likely range of transmitter frequencies. The following flip-flop circuit will divide the frequency by 2.

C-6 should be mica or other capacitor with minimal temperature coefficient. Check to verify frequency stability with temperature changes.

Select R-19 and R-24 as follows:

1. Stop the oscillation of U-2 by shorting C-6.
2. Adjust R-19 and R-24 so that the flip-flop oscillator free runs at about 3 KHz below the desired transmit frequency. The output should be a square wave with 50% duty cycle.
3. Remove the short from C-6 and observe that the flip-flop has locked to the correct frequency.
4. Check that the frequency adjustment can cover the necessary range while maintaining the locked condition. The output should be a symmetrical square wave.

"TX sample" is brought out to a BNC connector on the front panel. This output is used to check the transmit frequency.

Transmitter #2 (cont'd)

Parts List:

R-16	Select
R-17	10 K Trimpot
R-18	4.3 K
R-19	47 K
R-20	680 ohm
R-21	56 ohm
R-22	5.6 K
R-23	680 ohm
R-24	47 K
R-25	10 ohm
C-6	1000 pF mica
C-7	24 pF
C-8	24 pF
C-9	1000 pF
C-10	1000 pF
C-11	100 uF 16 V
C-12	100 uF 16 V
Q-6	2N4401
Q-7	2N4401
U-2	LM555CN
U-3	78L10AC

Transmitter # 3

The power supply operates at approximately 55 KHz.

Consult the data sheets of U-4 and U-5 to understand the details of the design.

Set R-33 for current limiting at slightly above the normal peak charging current. The peak charging rate occurs just after each transmit burst.

T-1 is wound on a "cool-mu" E core set part number 00K3515E040 with bobbin.

The winding is tri-filar with 13 turns of # 24 enamel wire. The three windings are connected as indicated in the schematic. Do not substitute core materials.

D-2 and D-3 are ultra-fast recovery diodes.

C-15 is a bank of three 2700 uF @ 25 VDC capacitors. Use high frequency, high ripple current types.

C-17 is a bank of four 2200 uF @ 35 VDC capacitors. Use high frequency, high ripple current types.

Parts List:

R-26	8.2 K
R-27	8.2 K
R-28	36 K
R-29	13 K
R-30	13 K
R-31	1 K
R-32	2 K
R-33	500 ohms trimpot
R-34	0.1 ohm 2 watt
R-35	2 ohm 2 watt

Transmitter #3 (cont'd)

C-13	1000 pF		U-4	LM3524DN
C-14	1000 uF 16 V		U-5	TPS2012P
C-15	2700 uF 25 V	3 units		
C-16	1000 uF 16 V		D-1	1N4003
C-17	2200 uF 35 V	4 units	D-2	MUR 120G
			D-3	MUR 120G
Q-8	IRF 540Z			
			T-1	See notes.

Transmitter #4

Consult the data sheet for U-6.

R-36, R-37, C-19, and C-20 are intended to suppress sharp high voltage spikes on the leading edge of the waveform at Q-9 and Q-10. Depending on the circuit layout and the quality of T-2, these networks may not be necessary.

R-38 is a 270 ohm, 2 watt, non inductive, resistor.

D-4 and D-5 are ultra fast recovery diodes.

Select C-21 as follows:

1. View the output of the receiver at the "receiver sample" jack.
2. Apply a CW signal at the operating frequency, to the sonar input terminals; between the chassis ground and only one of the input terminals while leaving the other terminal open.
3. Adjust the input level and gain control for a medium signal displayed on the scope. It should be in the linear range and not saturated.
4. Move the input lead from the signal source to the other sonar input terminal.
5. The level on the scope should be similar, indicating that the two input terminals are balanced in stray capacitance to ground. The value of C-21 can be selected to equalize these two indications. C-21 balances the capacitance of the output transformer windings which are on one side of the receiver input.
6. Check that the sensitivity of the sonar receiver, with both input terminals connected normally is 20 to 30 db greater than the level observed above. This verifies the balance and common mode rejection of the input circuit.

T-2 is wound on an Amidon Associates, Inc. E core set, part number EA-77-625. The primary is 15 turns of # 18 enameled wire, bi-filar wound. Connect as a center-tapped 30 turn winding. The secondary is 100 turns of #24 enameled wire. Adjust the number of turns on the secondary, as necessary, for the correct output level.

The secondary carries 500 V peak-to-peak. Be sure to adequately insulate the secondary from the primary.

Transmitter #4 (cont'd)

Parts List:

R-36	33 ohm		
R-37	33 ohm	U-6	TPS2012P
R-38	270 ohm 2 watt		
		D-4	MUR 120G
C-19	.022 uF 200 V	D-5	MUR 120G
C-20	.022 uF 200 V		
C-21	500 pf 500 V mica	T-2	See notes.
Q-9	IRF 540Z		
Q-10	IRF 540Z		

Motor #1

The quiescent condition, with no input from the tachometer, is a high level on pin 1 of U-1A.

Pulse width at Q-1 is 110 uS.

Parts List:

R-1	24 K		
R-2	91 ohm	C-1	.1 uF
R-3	24 K	C-2	100 uF 16 V
R-4	1 K	C-3	1000 pF
R-5	470 ohm		
R-6	200 K	Q-1	2N4401
R-7	3.3 K		
R-8	160 K		
R-9	1.3 K		

Motor #2

U-3 is a variable voltage regulator controlled by R-22 and R-21.

Typical range of adjustment is:
- 0 ohms = motor stop.
- 2 K ohms = motor fast.

If U-3 runs hot, install heatsink.

Motor #2 (cont'd)

Parts List:

R-20	220 ohm	C-10	100 uF 16 V
R-21	2 K Trimpot		
R-22	2 K Trimpot	U-3	LM317T

Motor #3

To adjust the gain of the servo feedback loop, select R-13 and C-4. The slope of the saw-tooth waveform controls the gain.

The voltage at R-14 controls the motor speed set point:

0.2 VDC slow
1.5 VDC nominal
4.5 VDC fast

The variable pulse width signal at pin 7 of U-1B is partially smoothed by C-8 and C-9. Do not attempt to further "filter" the motor drive voltage. Too much filter delay will cause oscillation of the motor speed.

The current limit circuit should function at slightly higher than normal current draw. Select R-19 if necessary. This protects the motor in case it is stalled for any reason.

If Q-2 runs hot, install a heat sink.

Parts List:

R-10	5.1 K	D-1	1N4148
R-11	10 K Trimpot	D-2	1N4003
R-12	10 K Trimpot	D-3	1N4003
R-13	91 K	D-4	1N4148
R-14	100 K		
R-15	200 K	U-1B	LM393NG
R-16	3.3 K	U-2	78L10AC
R-17	1.5 K		
R-18	1.5 K	Q-2	IRF 540Z
R-19	0.9 ohm 1 watt	Q-3	2N4401
C-4	.015 uF		
C-5	100 uF 16 V		
C-6	100 uF 16 V		
C-7	1000 uF 25 V		
C-8	.082 uF		
C-9	.027 uF		

Calibration #1

The pulse width at Q-2 is about 120 mS.

The pulse width at Q-5 should be 100uS

R-10 can be selected to set the maximum current output from the trigger output. This current limit will prevent damage from accidentally shorting the trigger output.

Q-7 is a darlington transistor.

The pulse width at Q-6 and Q-7 determines the duration of the distance marker line. It should be slightly longer than one full sweep at the longest range. For a 1000 foot range it would be 408 mS or longer.

Parts List:

R-1	5.1 K
R-2	910 ohm
R-3	3.0 K
R-4	13 K
R-5	910 ohm
R-6	110K
R-7	820 ohm
R-8	10 ohm
R-9	300 ohm
R-10	110 ohm
R-11	10 ohm
R-12	750 ohm
R-13	910 K
R-14	750 ohm
R-15	10 K
R-16	500 ohm Trimpot
R-17	10 K
R-18	15 K
R-19	62 ohm
R-20	3.3 K
R-21	Not used
R-22	20 K
R-23	15 K
R-24	150 K

C-1	100 uF 16 V
C-2	2200
C-3	1.0 uF
C-4	100 uF 16 V
C-5	1.0 uF
C-6	.01 uF
C-7	100 uF 16 V
D-1	1N4148
D-2	1N4148
Q-1	2N4401
Q-2	2N4401
Q-3	2N4401
Q-4	2N4403
Q-5	2N4401
Q-6	2N4401
Q-7	MPS A29 Darlington
Q-8	2N4401

Calibration #2

Select R-25 and R-26 for the correct frequencies at pin 3 of U-1.
For 14.8 second intervals, the frequency is 675.53 Hz
For 59.2 second intervals, the frequency is 168.88 Hz

The pulse at C-16 should be every 14.8 or 59.2 seconds

Parts List:

R-24	10 K Trimpot	C-11	10 uF 16 V
R-25	91 K	C-12	10 uF 16 V
R-26	12 K	C-13	10 uf 16 V
R-27	10 K Trimpot	C-14	100 uF 16 V
R-28	3.3 K	C-15	Not used
R-29	10 ohm		
R-30	10 ohm	Q-9	2N4401
R-31	15 K	Q-10	2N4401
R-32	1.2 K		
R-33	47 K	D-3	1N4148
R-34	47 K		
R-35	1.2 K	U-1	LM555CN
R-51	10 ohm	U-2	CD4017BE
		U-3	CD4017BE
C-8	.082	U-4	CD4017BE
C-9	100 uF 16 V	U-5	CD4017BE
C-10	10 uF 16 V		

Calibration #3

Select R-36 for a period of 20.4 mS at pin 3 of U-6. This is the range calibration.

Select C-18 for the desired thickness of the range lines.

Parts List:

R-36	Select	R-44	240 K
R-37	50K Trimpot	R-45	39 K
R-38	22 ohm	R-46	1.2 K
R-39	1.5 K	R-47	1 K
R-40	360 ohm	R-48	10 ohm
R-41	150 K	R-49	10 ohm
R-42	910 ohm	R-50	1 K Trimpot
R-43	Jumper		

Calibration #3 (cont'd)

C-16	Not used
C-17	100 uF 16 V
C-18	4700 pF
C-19	.1 uF
C-20	.027 uF
C-21	470 uF 25 V
C-22	100 16V
Q-11	2N4401
Q-12	2N4403
D-4	1N4003
U-6	LM555CN
U-7	LM555CN
U-8	78L10AC
U-9	78L10AC
U10	78L10AC

Stylus driver

U-2 should oscillate at 18 KHz. Select R-15 as necessary.

Pulse width at Q-2 is 10 uS. Increase this pulse width if more power is required.

T-1 is wound on a "cool-mu" E core set part number 00K3515E040 with bobbin. The primary winding is 10 turns of #20 enameled wire. The secondary is 40 turns of #26 enameled wire. Connect as indicated on the schematic.

The current limit controls the drive to Q-3. Select R-17 for a current limit that will not smoke the paper when a saturated signal is being printed. The energy stored in C-3 will allow printing short pulses very dark but long pulses will be controlled by the current limit system.

C-5 is a bank of three 1200 uF @ 25 VDC capacitors.

Q-3 requires a heat sink.

Adjust R-4 bias for a quiescent voltage on Q-1 collector well below the turn-on bias of Q-3. Check for temperature sensitivity of this adjustment.

Parts List:

R-1	430 ohm
R-2	430 ohm
R-3	7.5 K
R-4	200 ohm Trimpot
R-5	2.2 K
R-6	2 K
R-7	910 ohm
R-8	56 ohm
R-9	18 K
R-10	Not used
R-11	39 K
R-12	3 ohm 2 watt
R-13	56 ohm
R-14	75 K
R-15	39 K
R-16	430 ohm
R-17	Select

Stylus Driver (cont'd)

C-1	100 uF 16 V
C-2	680 pF
C-3	1000 pF
C-4	1200 uF 25 V
C-5	1200 uF 25 V 3 units
D-1	1N4148
D-2	1N4148
D-3	1N4148
D-4	1N4148
D-5	1N4148
D-6	1N4003

U-1	4N35
U-2	LM555CN
U-3	78L10AC
Q-1	2N4401
Q-2	2N4401
Q-3	IRF 540Z
T-1	See notes.

Notes